US009068859B2

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Dwyer et al.

(10) **Patent No.: US 9,068,859 B2**
(45) **Date of Patent: Jun. 30, 2015**

(54) **MAGNETIC FIELD SENSORS AND RELATED TECHNIQUES PROVIDE A SELF-TEST BY COMMUNICATING SELECTED ANALOG OR DIGITAL SAMPLES OF A PROXIMITY SIGNAL**

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(73) Assignee: **Allegro Microsystems, LLC**, Worcester, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 252 days.

(21) Appl. No.: **13/526,103**

(22) Filed: **Jun. 18, 2012**

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(51) **Int. Cl.**
G01B 7/30 (2006.01)
G01D 5/14 (2006.01)
G01D 3/08 (2006.01)

(52) **U.S. Cl.**
CPC . ***G01D 5/145*** (2013.01); ***G01D 3/08*** (2013.01)

(58) **Field of Classification Search**
CPC G01D 3/08; G01D 5/145; G01M 1/00
USPC 324/207.2, 207.21, 207.25, 207.26
See application file for complete search history.

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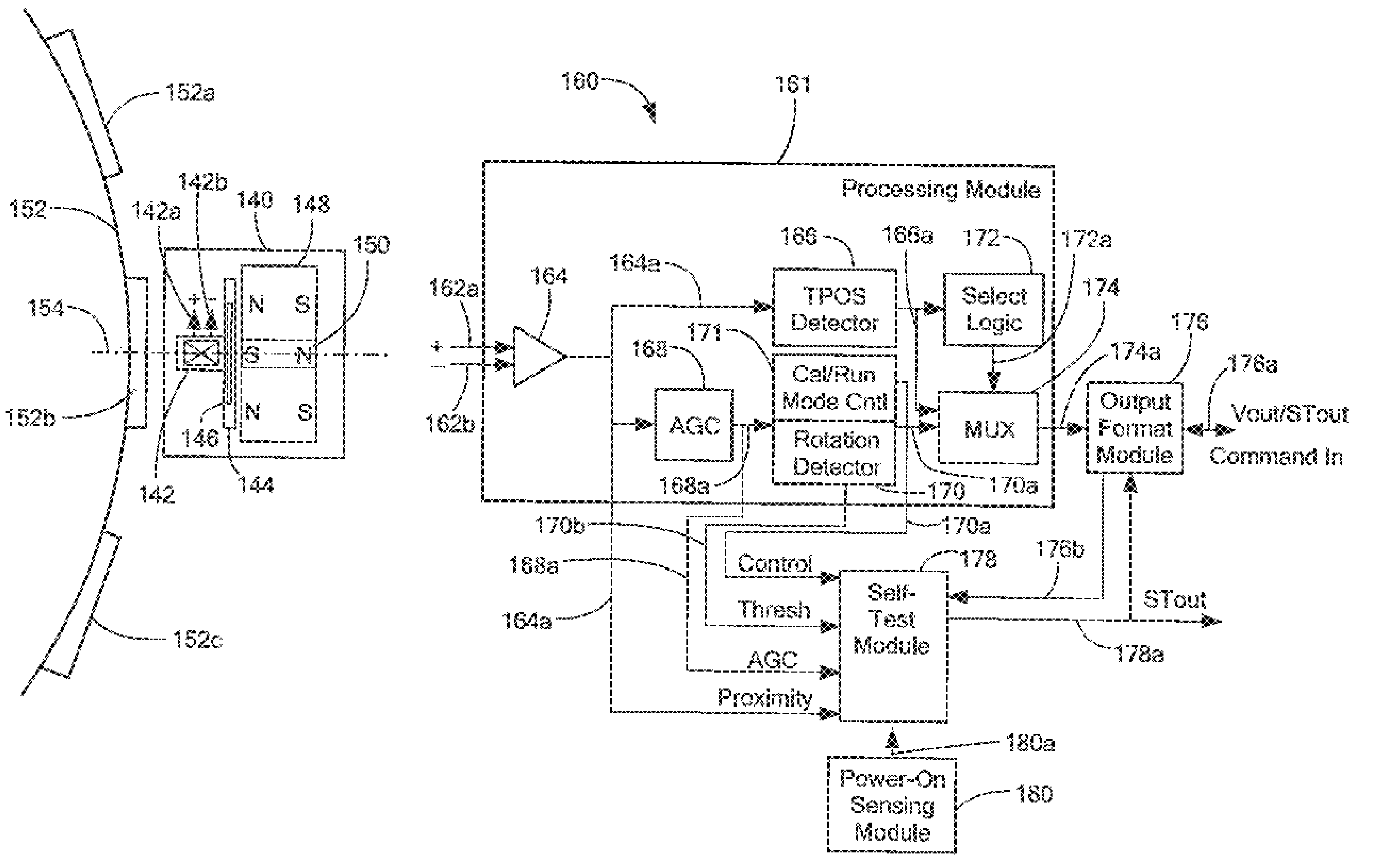
Primary Examiner — Jay Patidar
(74) *Attorney, Agent, or Firm* — Daly, Crowley, Mofford & Durkee, LLP

(57) **ABSTRACT**

Magnetic field sensors and related techniques can identify passing conditions, failing conditions, and marginal conditions of a sensed object. A magnetic field sensor used in the techniques can have a substrate and can have one or more magnetic field sensing elements disposed on the substrate that are configured to generate a proximity signal responsive to a proximity of the sensed object. The magnetic field sensor can have a self-test module disposed on the substrate, coupled to receive the proximity signal, configured to sample the proximity signal, by analog sampling or digitally converting, to generate a plurality of analog samples or a plurality of digital samples, respectively, each digital sample comprising a plurality of digital bits, configured to select samples from among the plurality of analog or digital samples, and configured to communicate the selected samples to outside of the magnetic field sensor.

21 Claims, 24 Drawing Sheets



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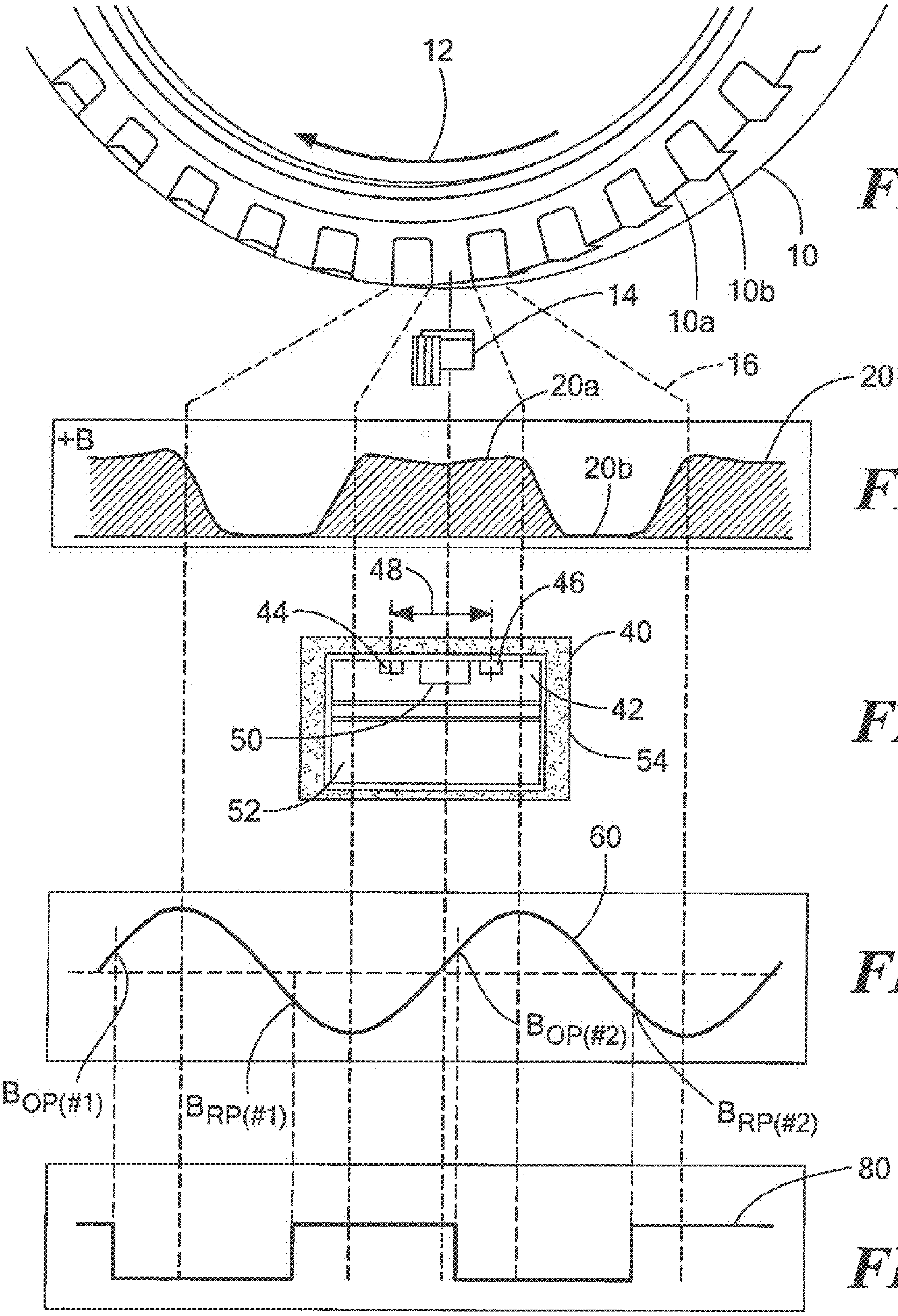

FIG. 1

FIG. 1A

FIG. 1B

FIG. 1C

FIG. 1D

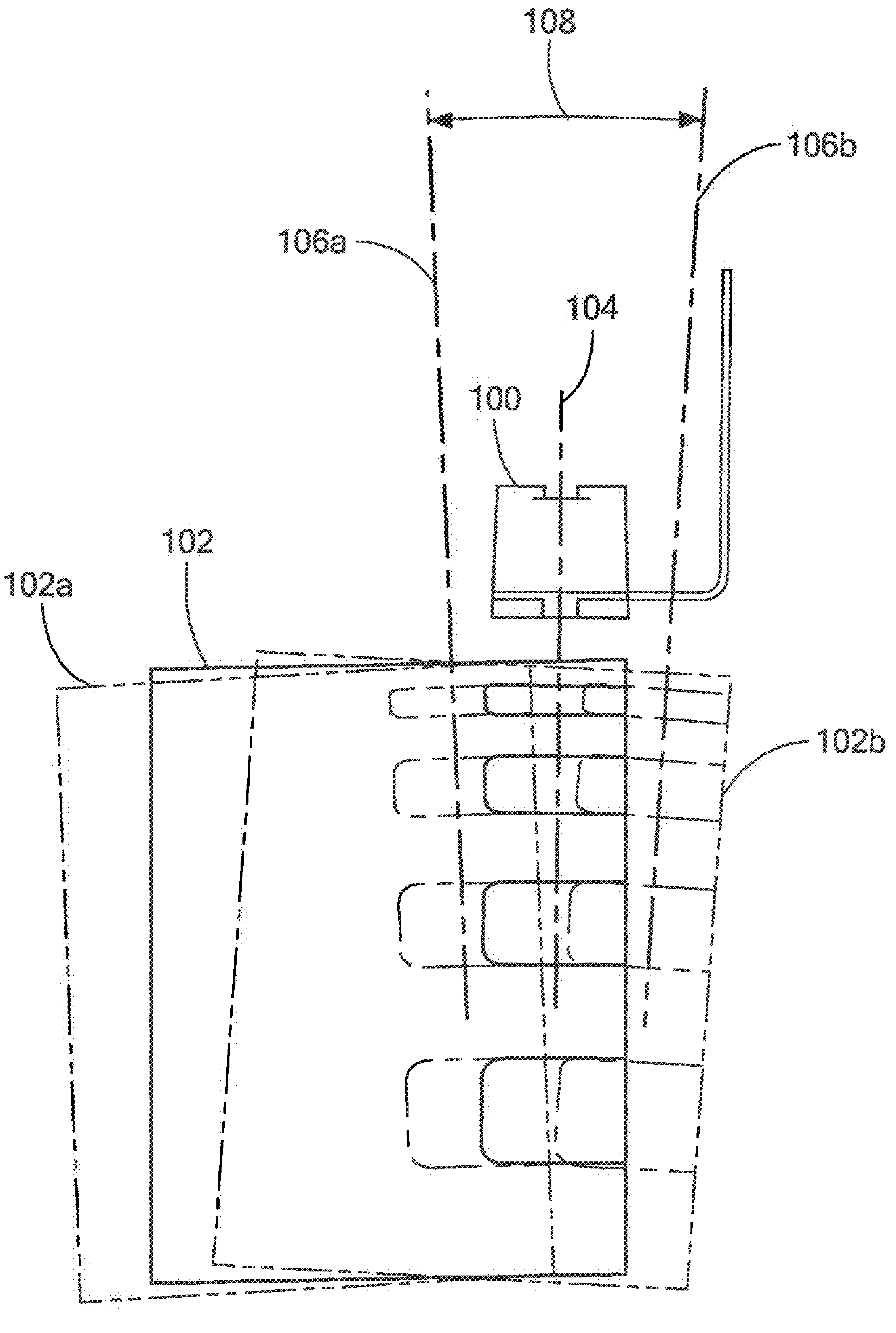

FIG. 2

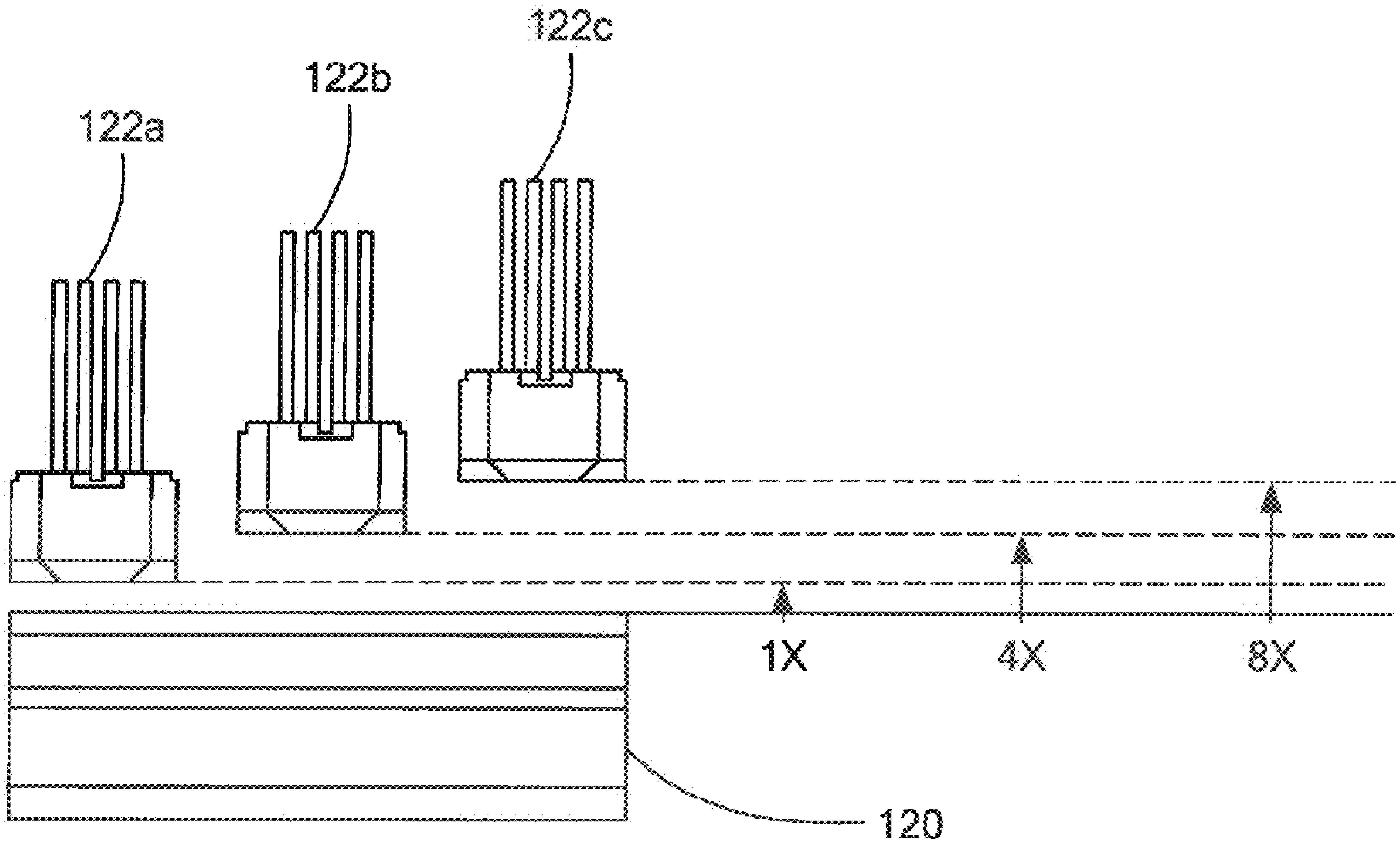

FIG. 2A

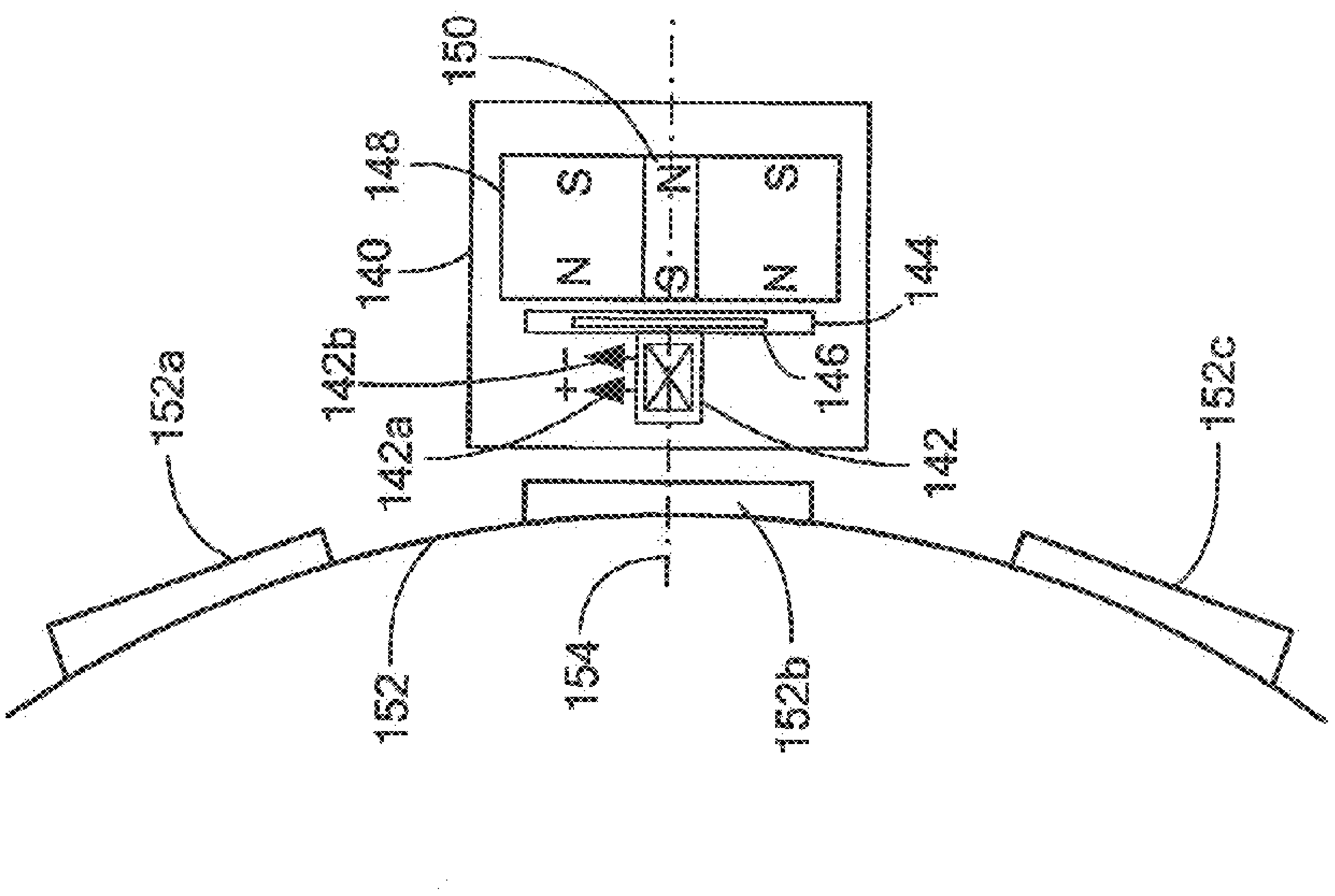
152a
152c
142b
142a
142
140
148
150
144
146
N
S
S
N
N
S
+
-
152
154
152b

FIG. 3

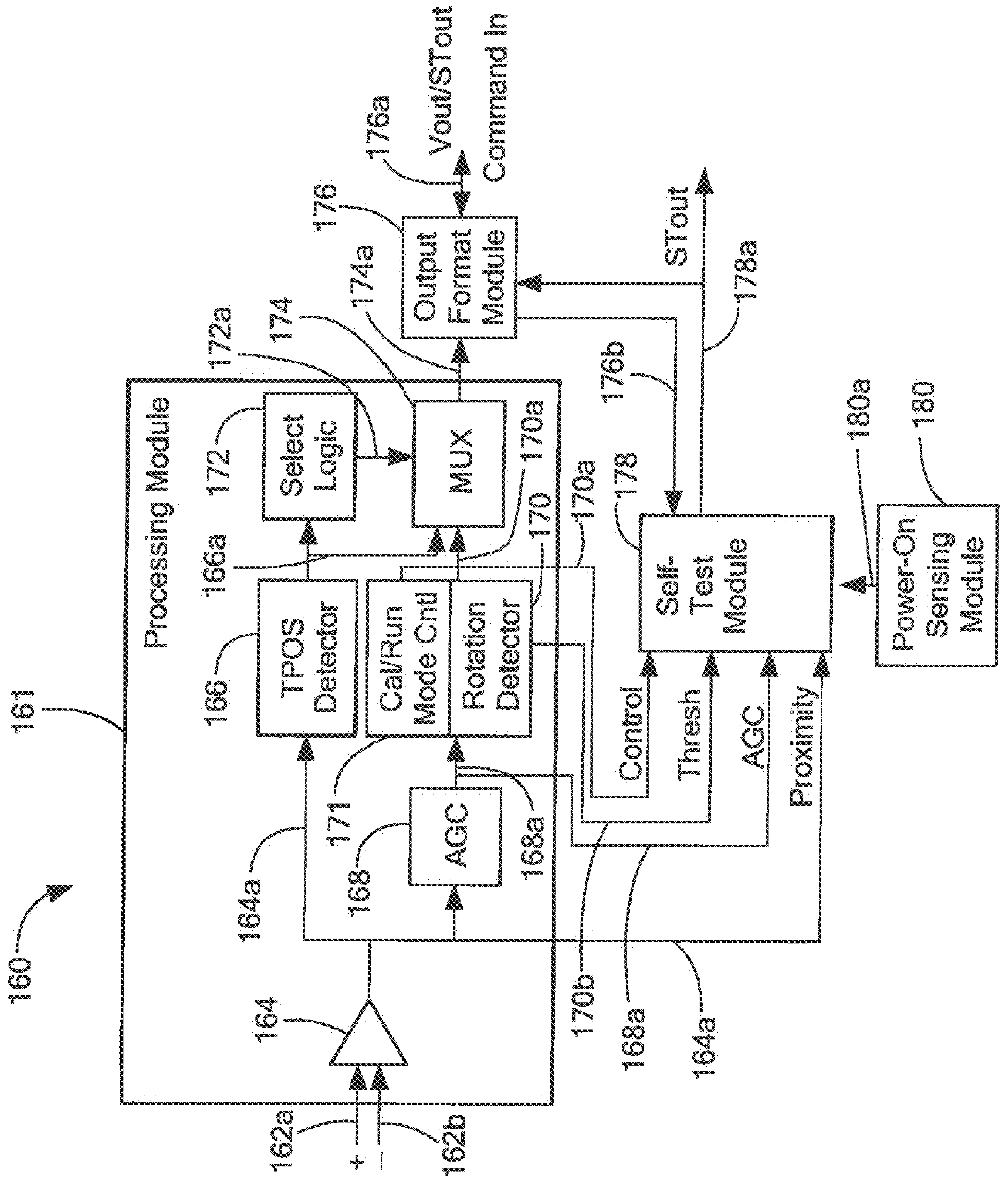
160
161
Processing Module
162a
162b
+
-
164
164a
168
AGC
168a
171
166
TPOS Detector
166a
Cal/Run Mode Cntl
Rotation Detector
170
170a
170b
172
Select Logic
172a
MUX
174
174a
Output Format Module
176
176a
176b
Vout/STout
Command In
Self-Test Module
178
178a
STout
Control
Thresh
AGC
Proximity
Power-On Sensing Module
180
180a

FIG. 3A

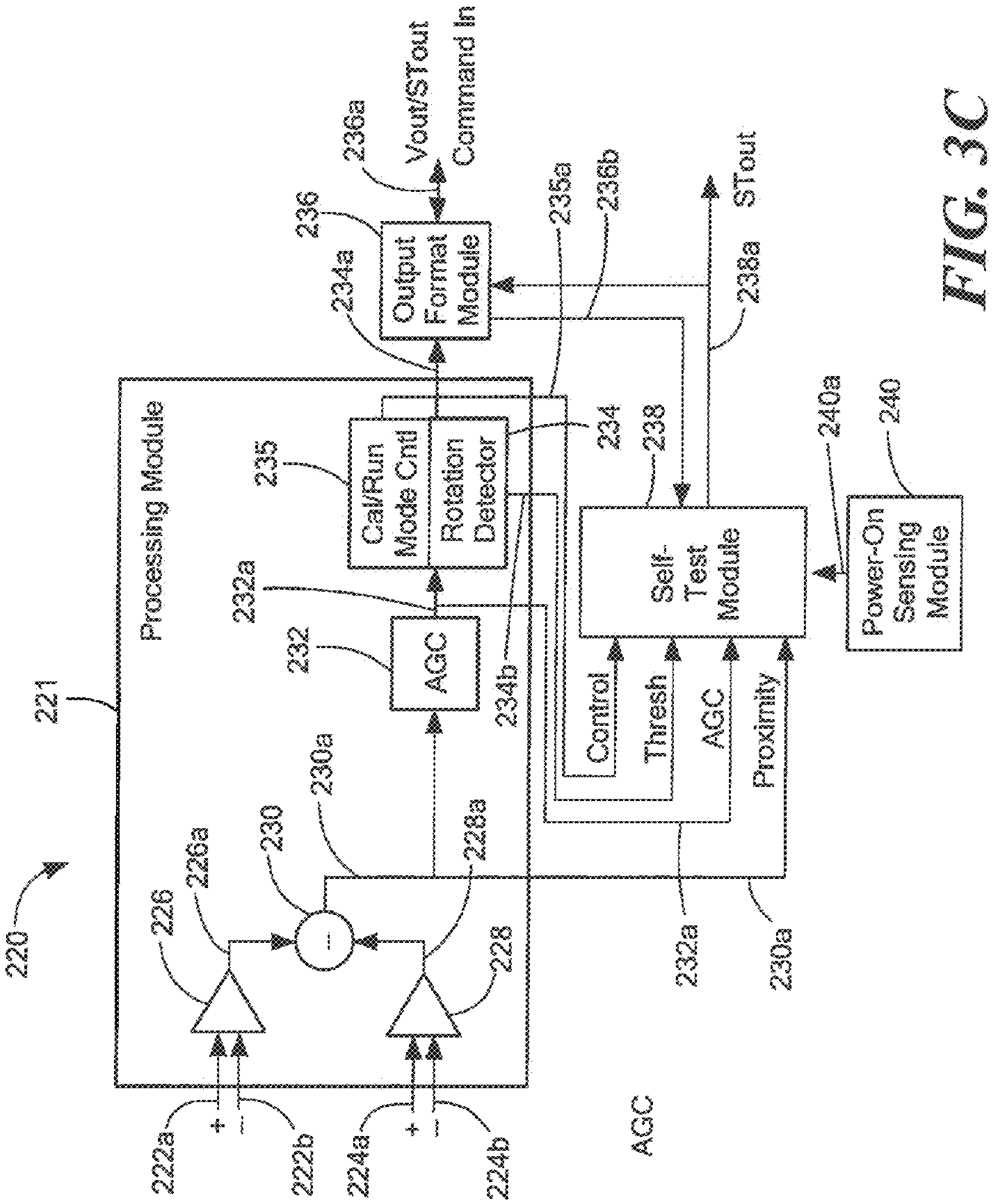
220
221
Processing Module
222a
222b
224a
224b
+
−
+
−
226
226a
228
228a
230
230a
232
232a
AGC
Cal/Run Mode Cntl
235
Rotation Detector
234
234a
234b
235a
236
Output Format Module
236a
236b
Vout/STout
Command In
Self-Test Module
238
238a
STout
Control
Thresh
AGC
Proximity
232a
230a
Power-On Sensing Module
240
240a
AGC

FIG. 3C

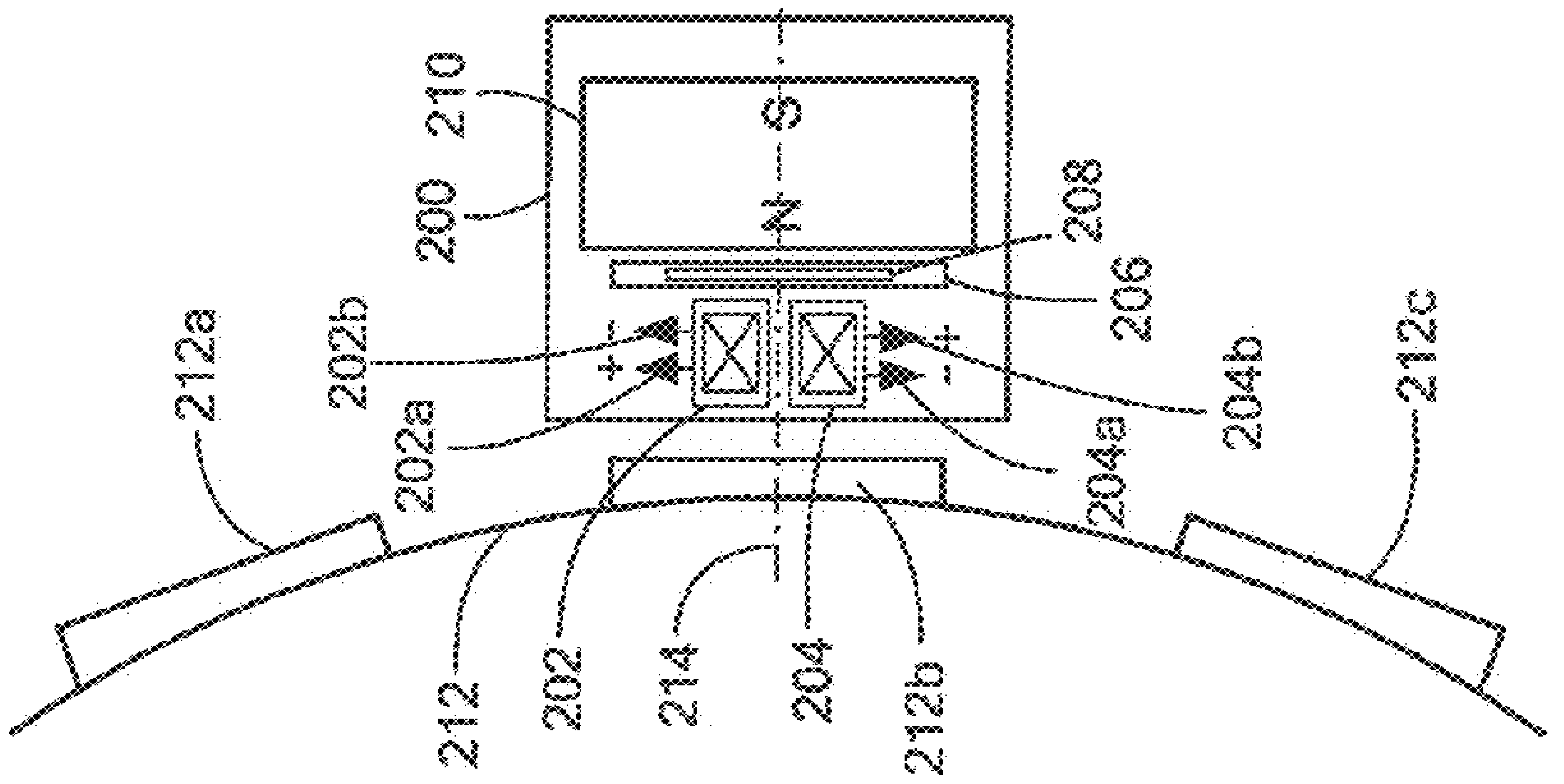
212a
212c
200
210
N
S
208
206
202b
202a
+
−
−
+
204a
204b
212
202
214
204
212b

FIG. 3B

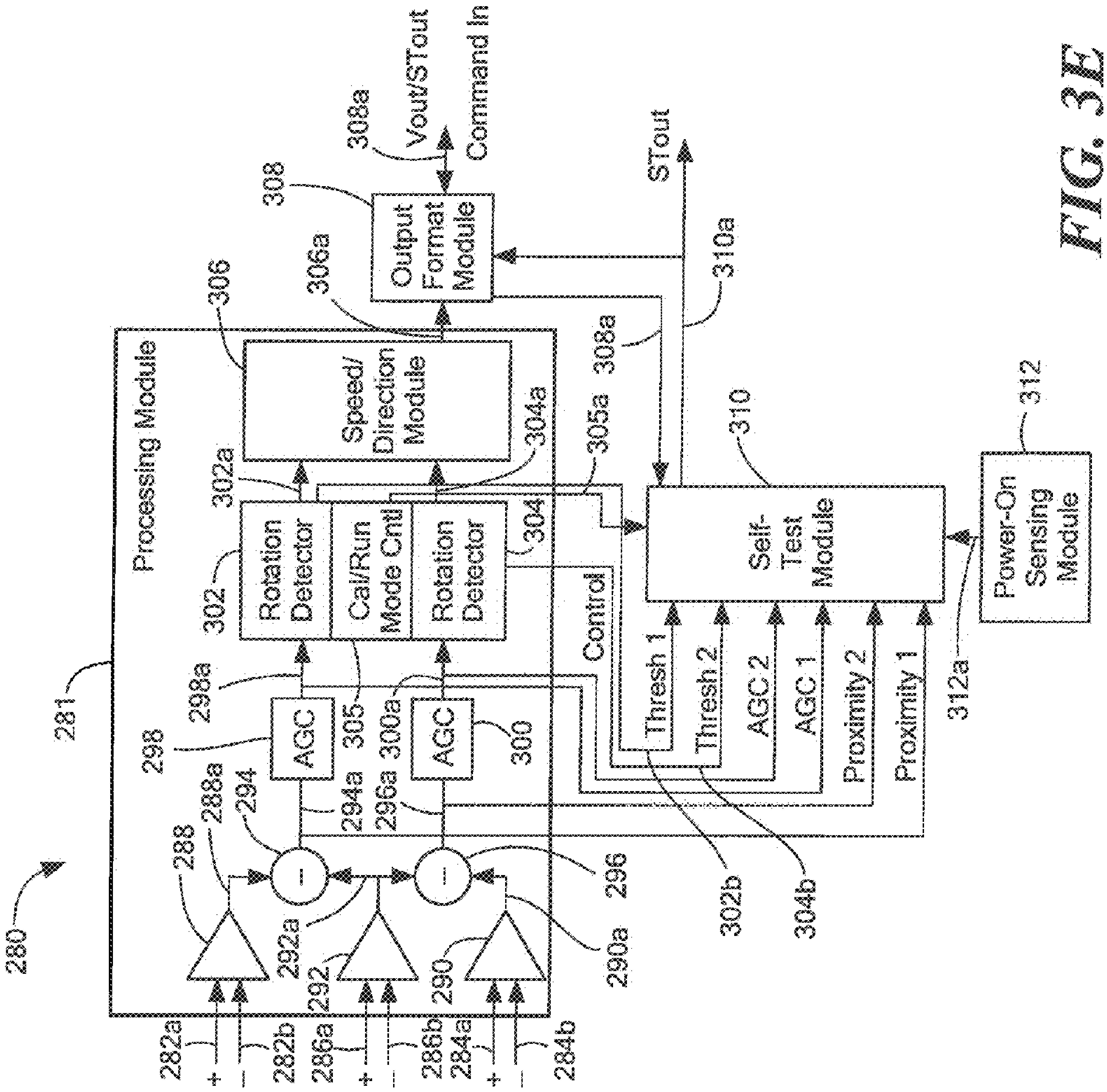
280
281
Processing Module
282a
282b
286a
286b
284a
284b
288
288a
292
292a
290
290a
294
294a
296
296a
298
298a
300
300a
AGC
AGC
302
302a
302b
Rotation Detector
Cal/Run Mode Cntl
305
305a
Rotation Detector
304
304a
304b
Control
Thresh 1
Thresh 2
AGC 2
AGC 1
Proximity 2
Proximity 1
306
306a
Speed/ Direction Module
308
308a
Output Format Module
Vout/STout
Command In
STout
310
310a
Self-Test Module
312
312a
Power-On Sensing Module

FIG. 3E

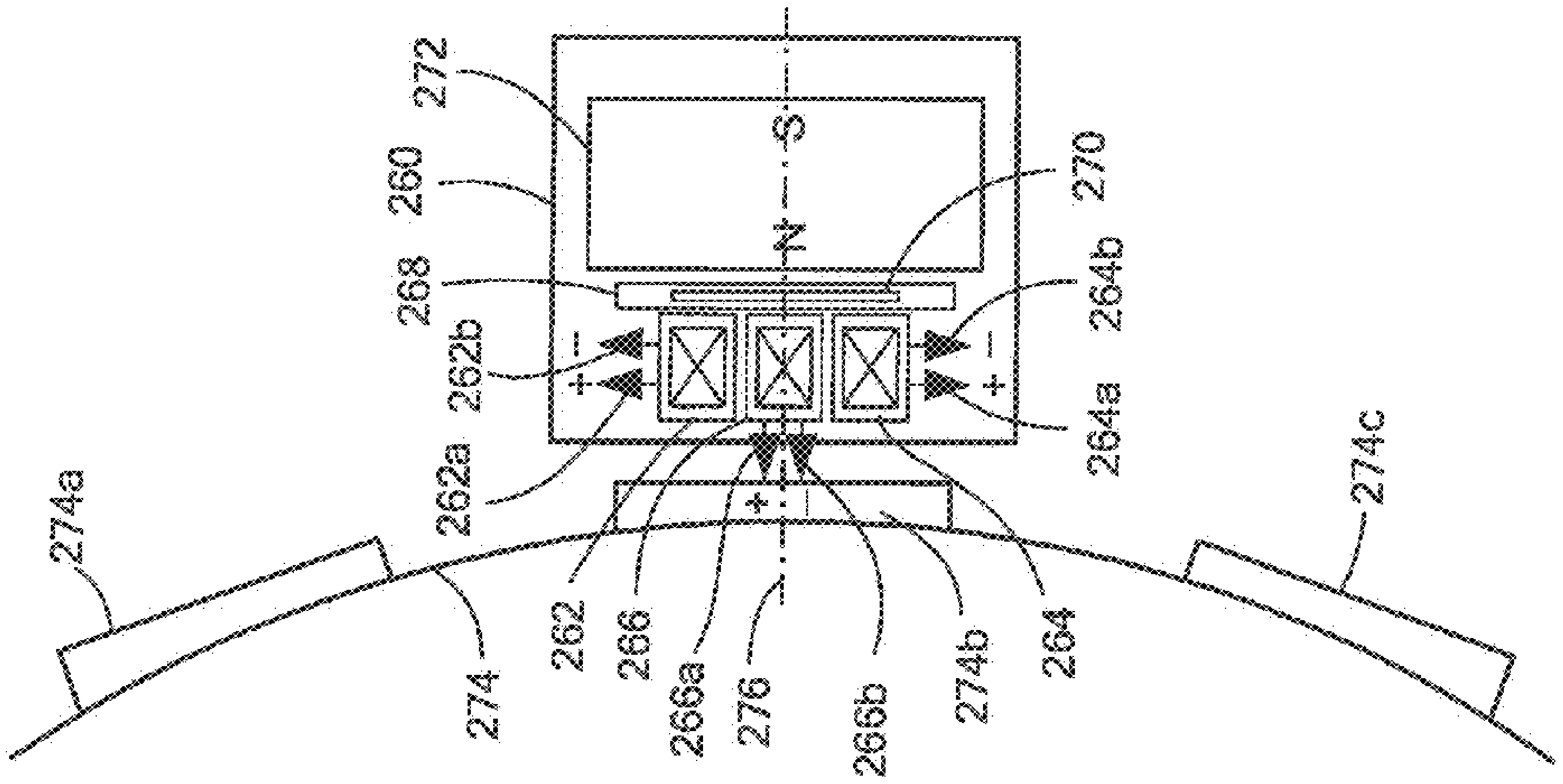
260
272
S
N
268
270
262b
262a
264b
264a
262
266
266a
276
266b
274b
264
274
274a
274c

FIG. 3D

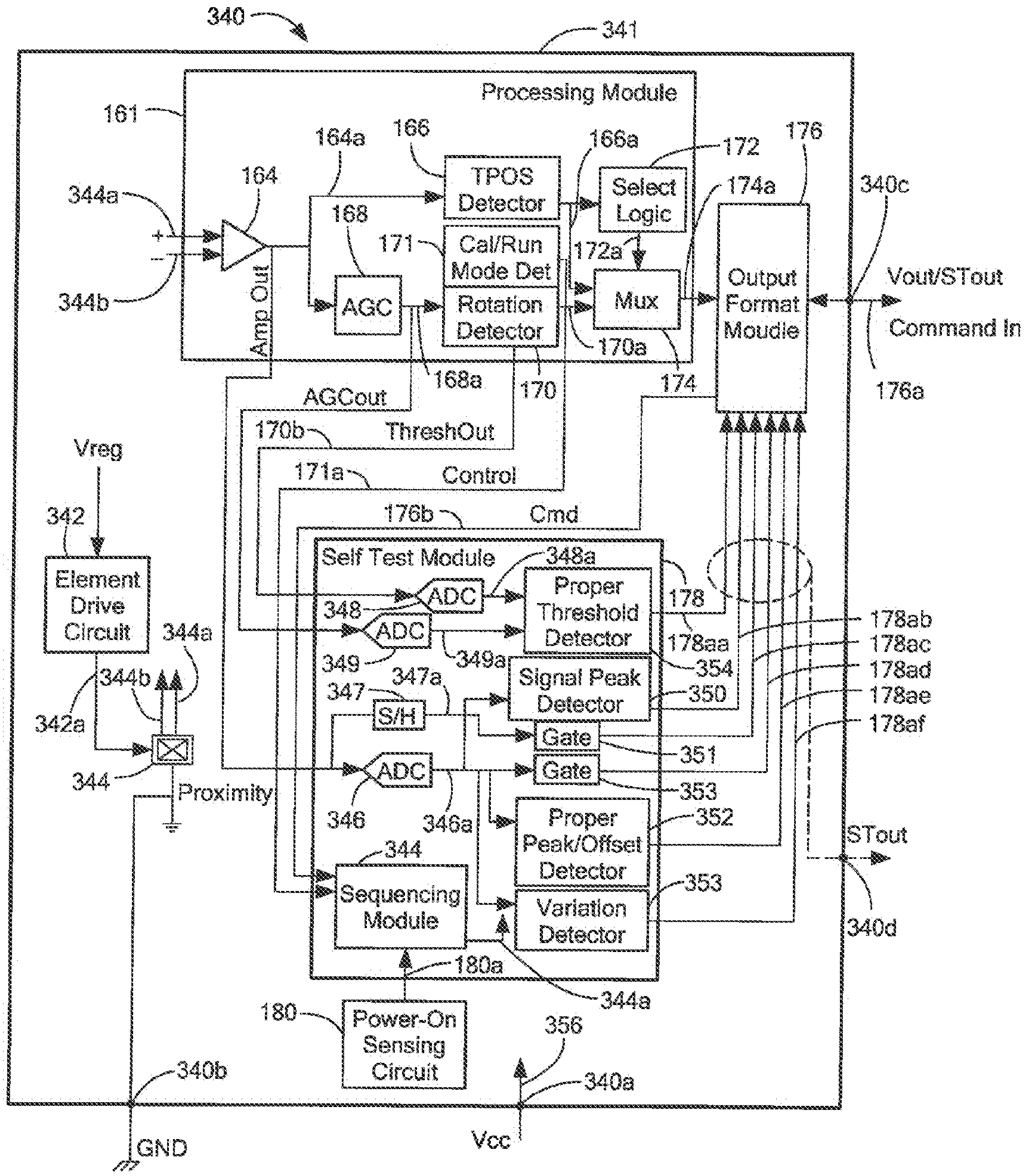
340
341
Processing Module
161
166
164a
166a
172
176
164
TPOS Detector
Select Logic
174a
340c
344a
168
171
Cal/Run Mode Det
172a
Output Format Moudle
Vout/STout
AGC
Rotation Detector
Mux
Command In
344b
Amp Out
170a
168a
170
174
176a
AGCout
170b
ThreshOut
171a
Control
Vreg
176b
Cmd
342
Self Test Module
348a
Element Drive Circuit
ADC
Proper Threshold Detector
178
348
ADC
178ab
344a
349
349a
178aa
178ac
354
178ad
344b
347a
Signal Peak Detector
350
178ae
347
S/H
Gate
178af
342a
351
344
ADC
Gate
353
Proximity
346
346a
352
Proper Peak/Offset Detector
STout
344
Sequencing Module
353
Variation Detector
340d
180a
344a
180
Power-On Sensing Circuit
356
340b
340a
GND
Vcc

FIG. 4

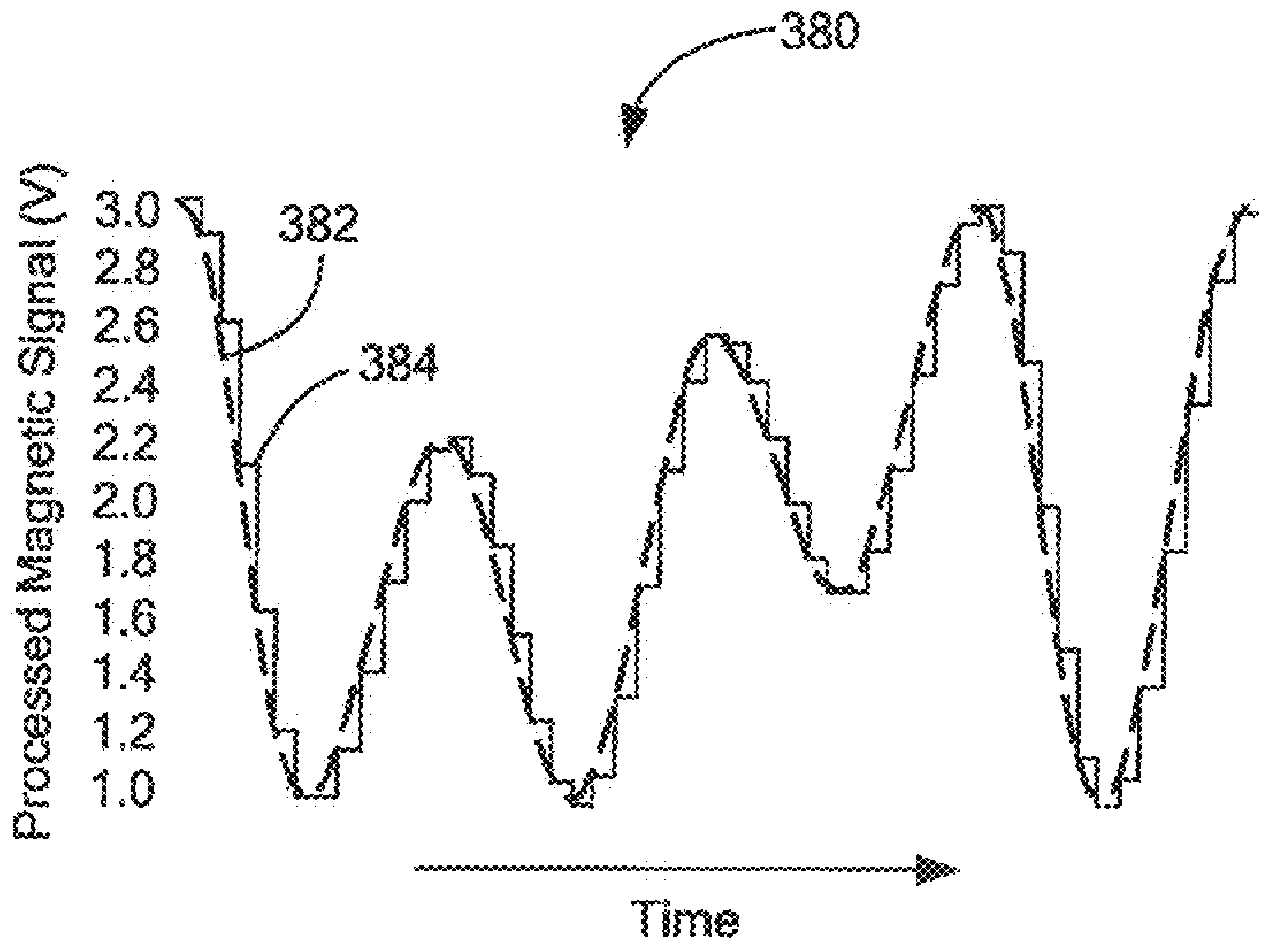

FIG. 5

Sampled Analog Voltage	...	3.000	2.848	2.681	2.132	1.641	390
	1.245	1.152	1.152	1.178	1.438	1.716	
	2.012	2.175	2.218	2.218	2.095	1.860	
	1.565	1.281	1.078	1.000	1.000	1.098	
	1.357	1.722	2.105	2.402	2.558	2.558	
	2.418	2.218	2.001	1.817	1.704	1.704	
	1.841	2.108	2.432	2.728	2.938	2.987	
	2.987	2.834	2.431	1.994	1.518	1.162	
	1.000	1.000	1.087	1.395	1.852	2.331	
	2.742	2.965	...				

DAC State	...	1011	1010	1001	0110	0100	400
	0010	0001	0001	0010	0100	0101	
	0111	0111	1000	0111	0110	0101	
	0011	0010	0001	0001	0001	0010	
	0011	0101	0111	1001	1001	1000	
	1000	0111	0110	0101	0100	0101	
	0110	0111	1001	1010	1011	1011	
	1011	1010	1000	0110	0011	0001	
	0001	0001	0010	0100	0110	1000	
	1010	1011	...				

DAC Peaks	...	1011	0001	1000	0001	1001	410
	0100	1011	0001	1011	...		

FIG. 5A

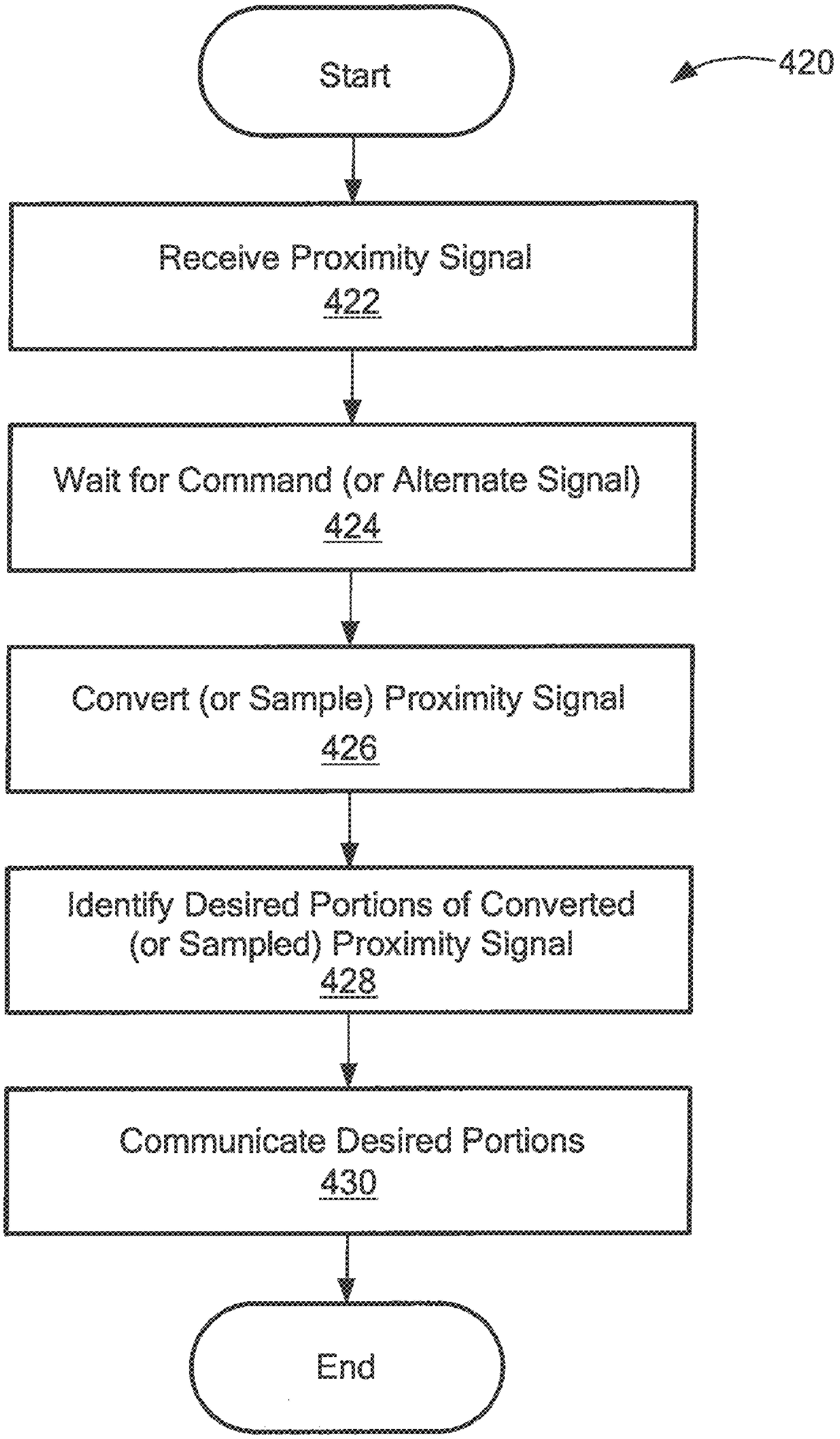
420
Start
Receive Proximity Signal
422
Wait for Command (or Alternate Signal)
424
Convert (or Sample) Proximity Signal
426
Identify Desired Portions of Converted
(or Sampled) Proximity Signal
428
Communicate Desired Portions
430
End

FIG. 6

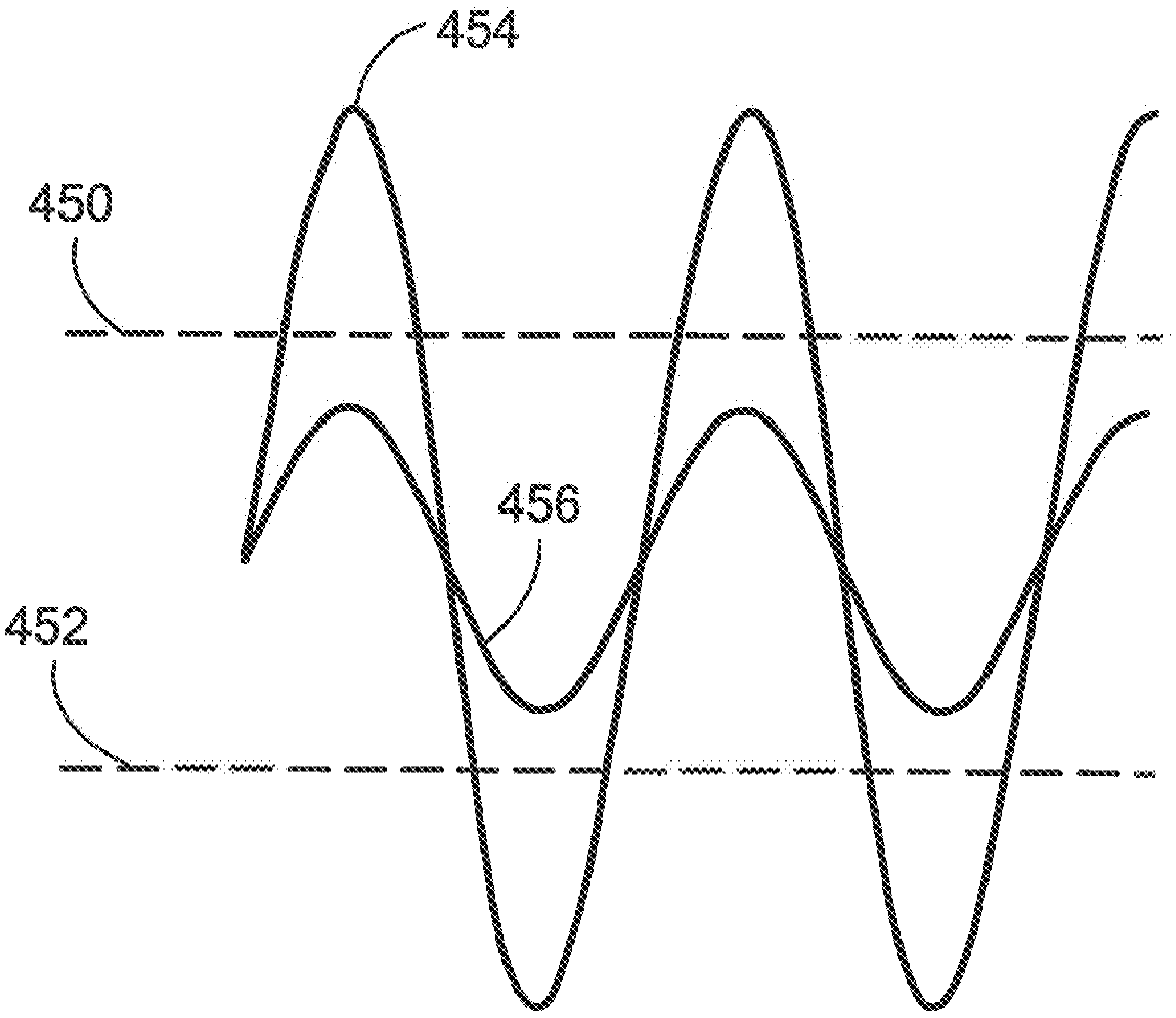

FIG. 7

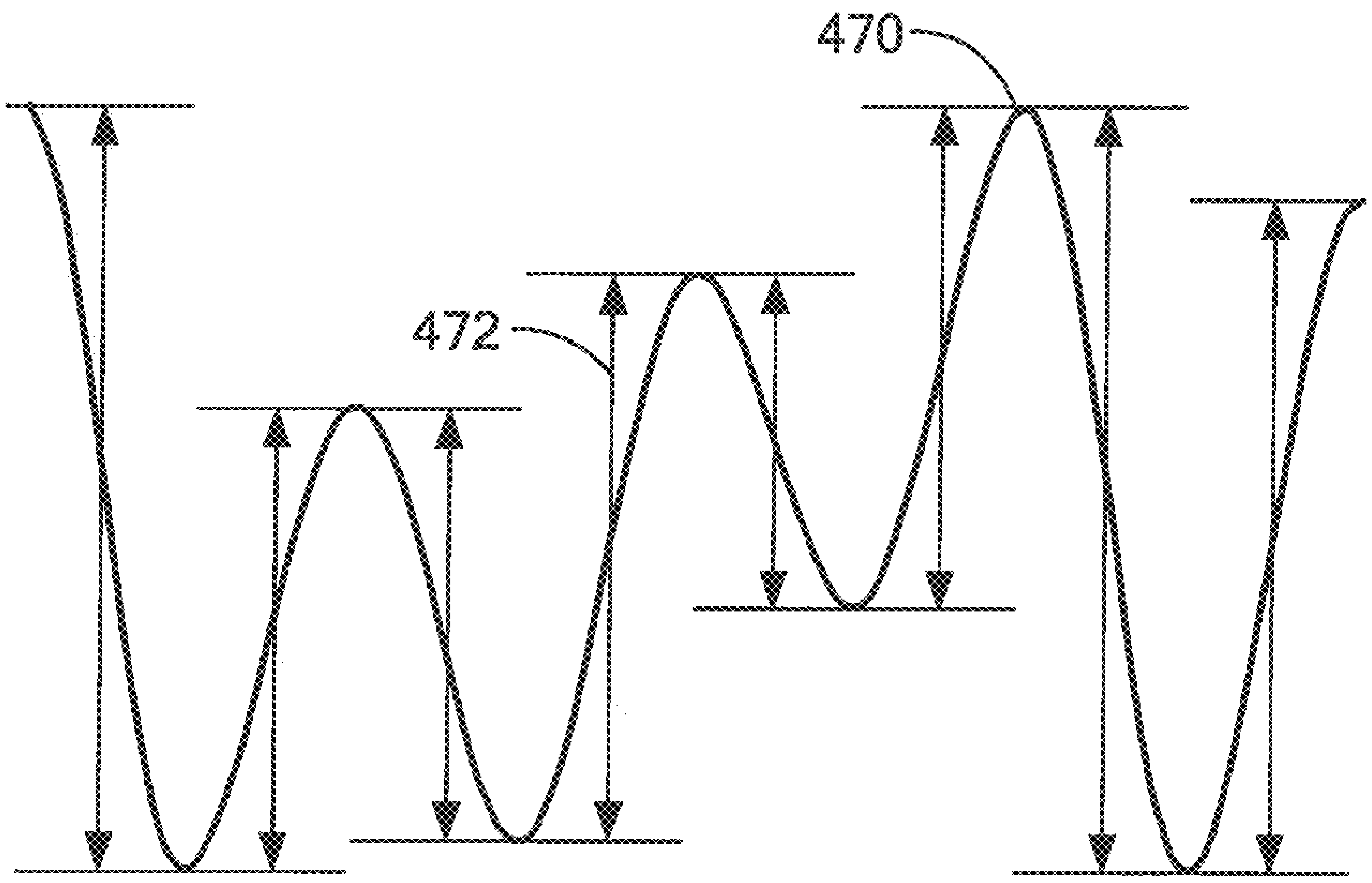

FIG. 8

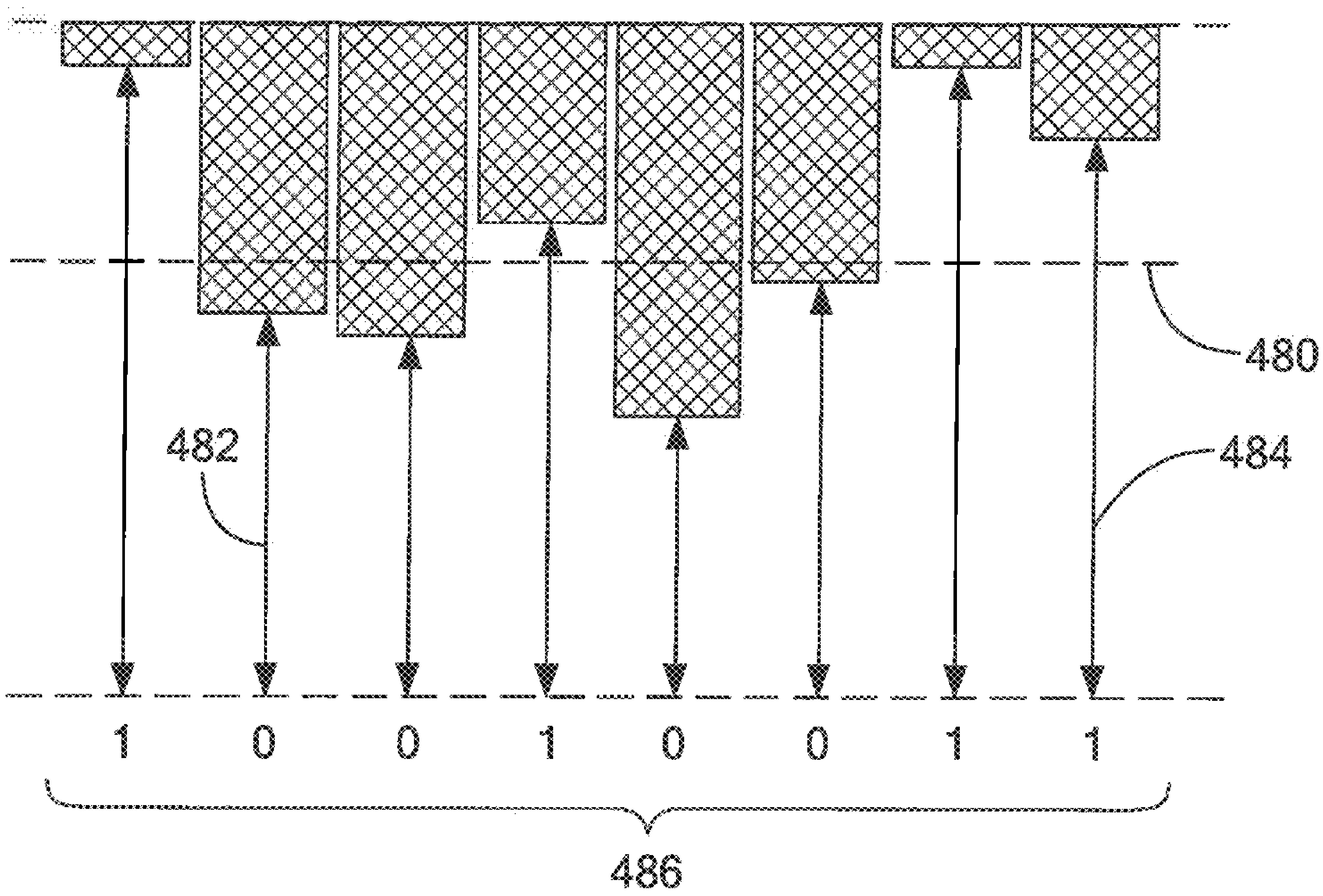

FIG. 8A

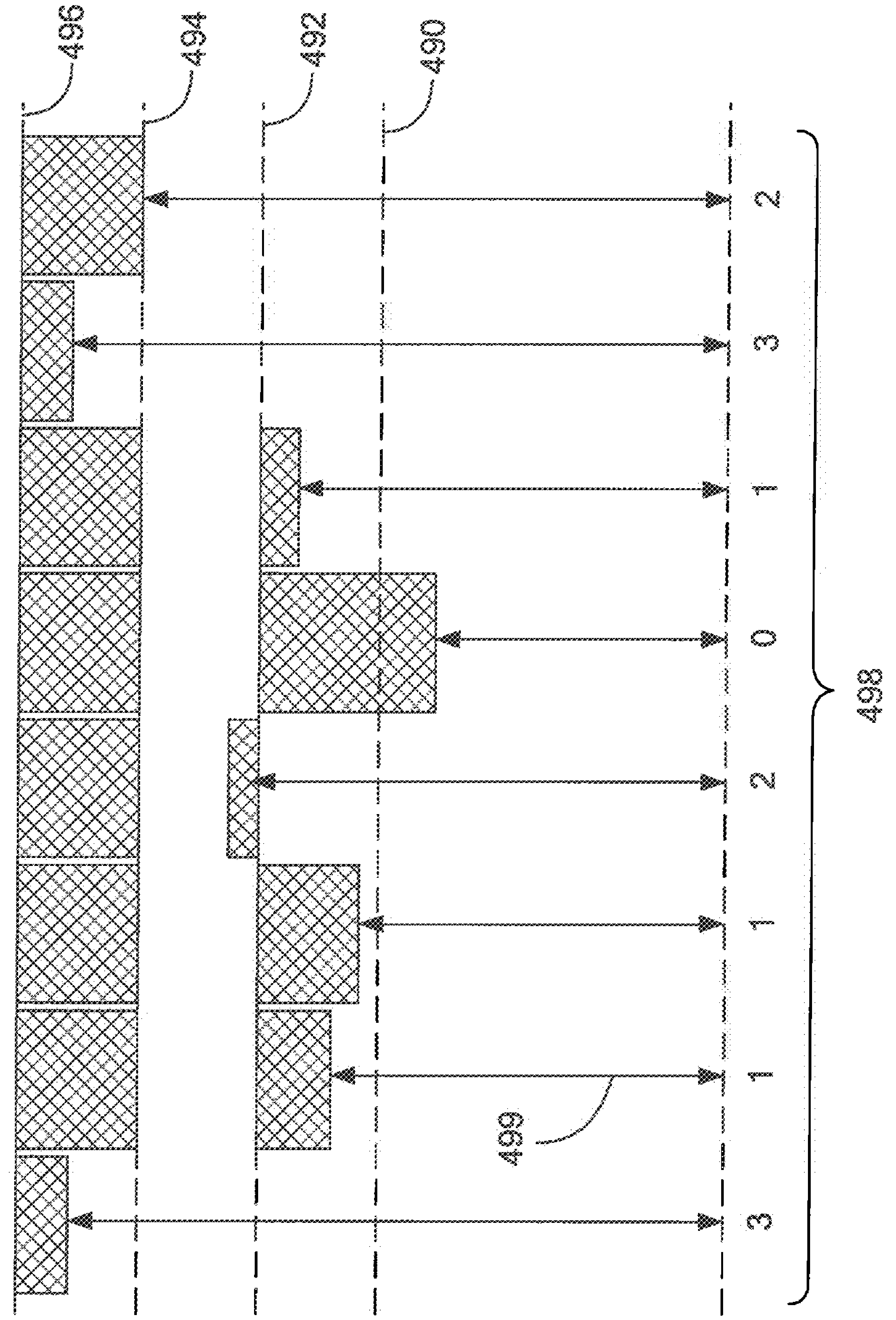

FIG. 9

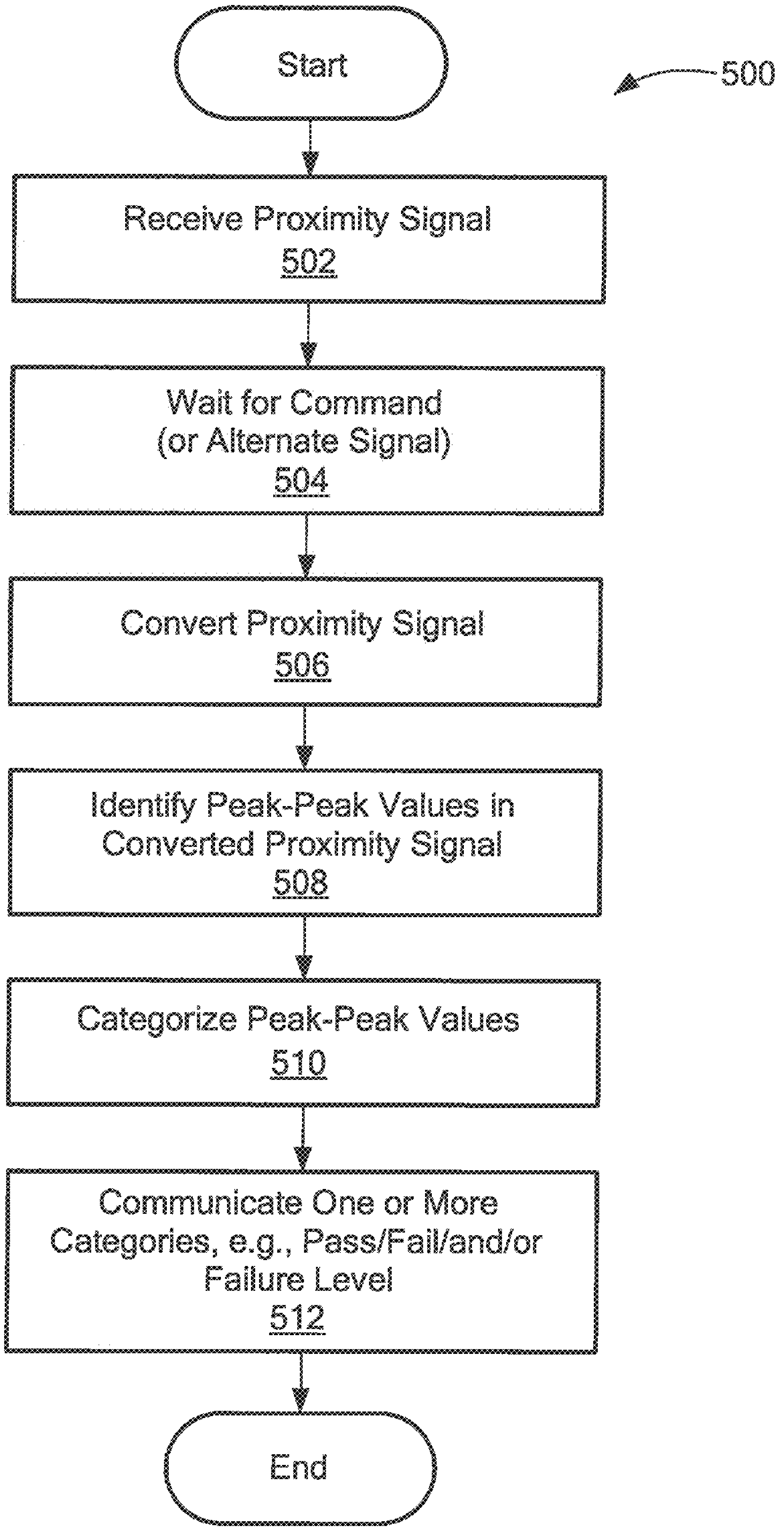
Start
500
Receive Proximity Signal
502
Wait for Command
(or Alternate Signal)
504
Convert Proximity Signal
506
Identify Peak-Peak Values in
Converted Proximity Signal
508
Categorize Peak-Peak Values
510
Communicate One or More
Categories, e.g., Pass/Fail/and/or
Failure Level
512
End

FIG. 10

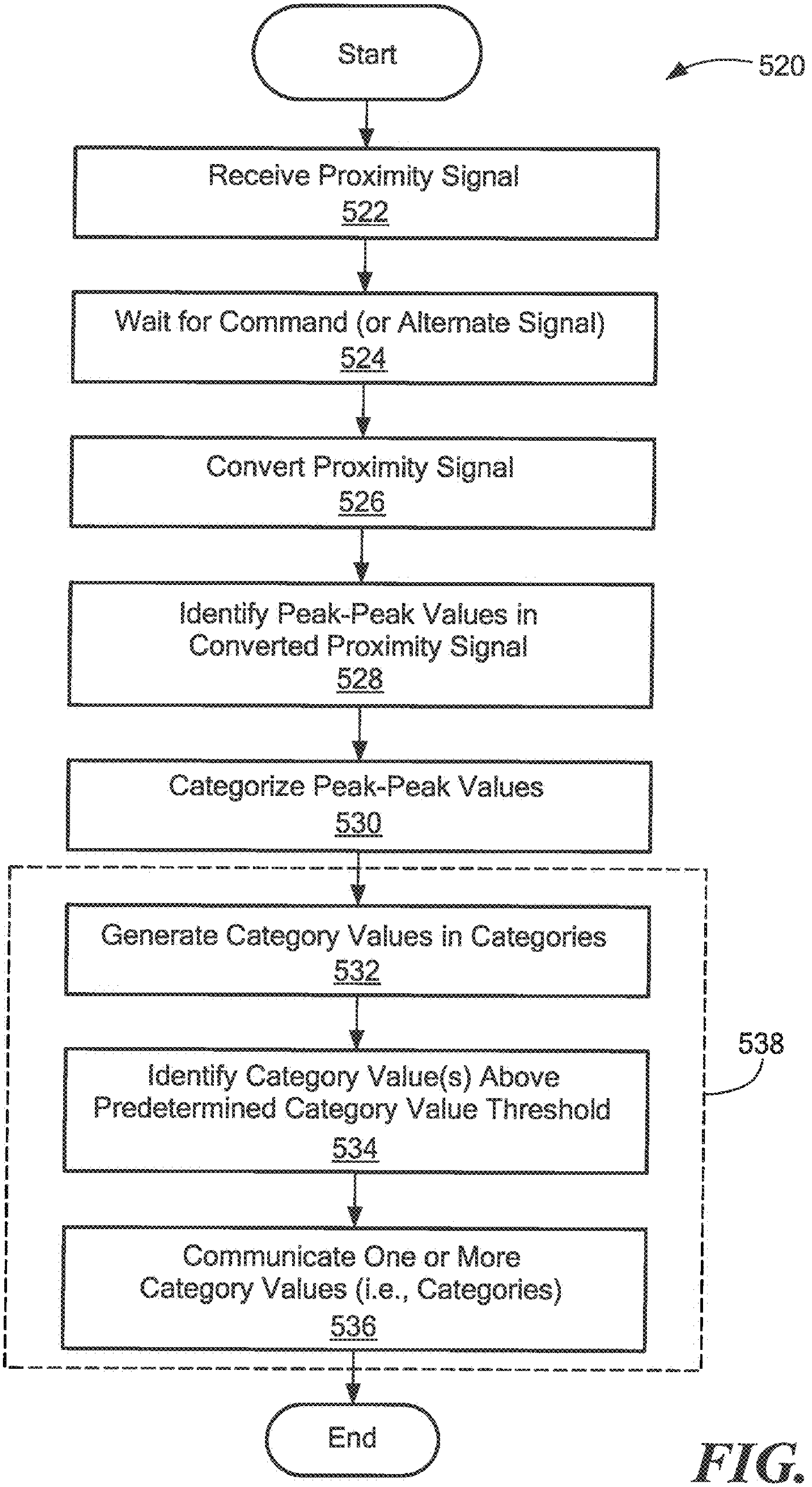
Start
520
Receive Proximity Signal
522
Wait for Command (or Alternate Signal)
524
Convert Proximity Signal
526
Identify Peak-Peak Values in Converted Proximity Signal
528
Categorize Peak-Peak Values
530
Generate Category Values in Categories
532
538
Identify Category Value(s) Above Predetermined Category Value Threshold
534
Communicate One or More Category Values (i.e., Categories)
536
End

FIG. 10A

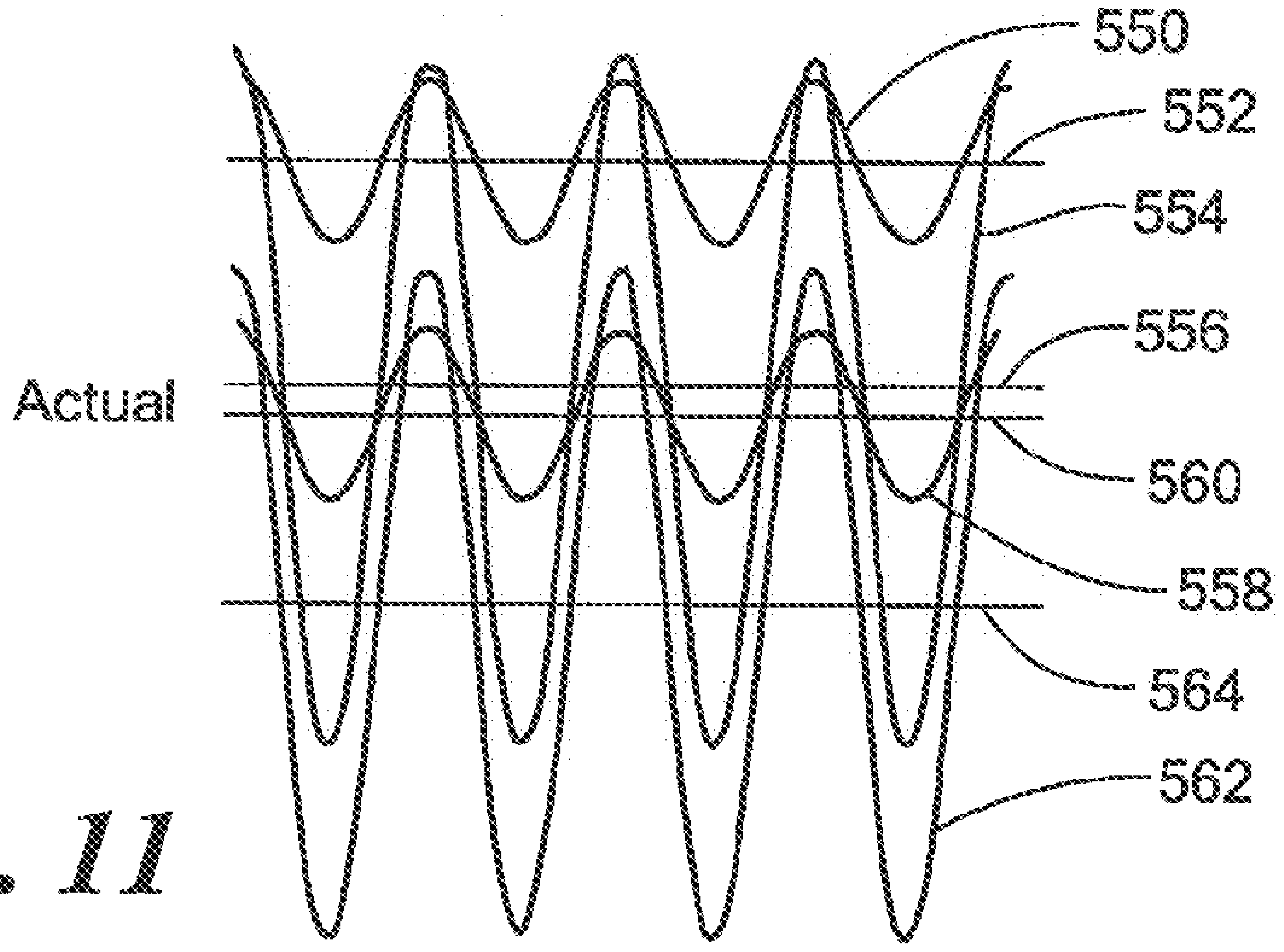

FIG. 11

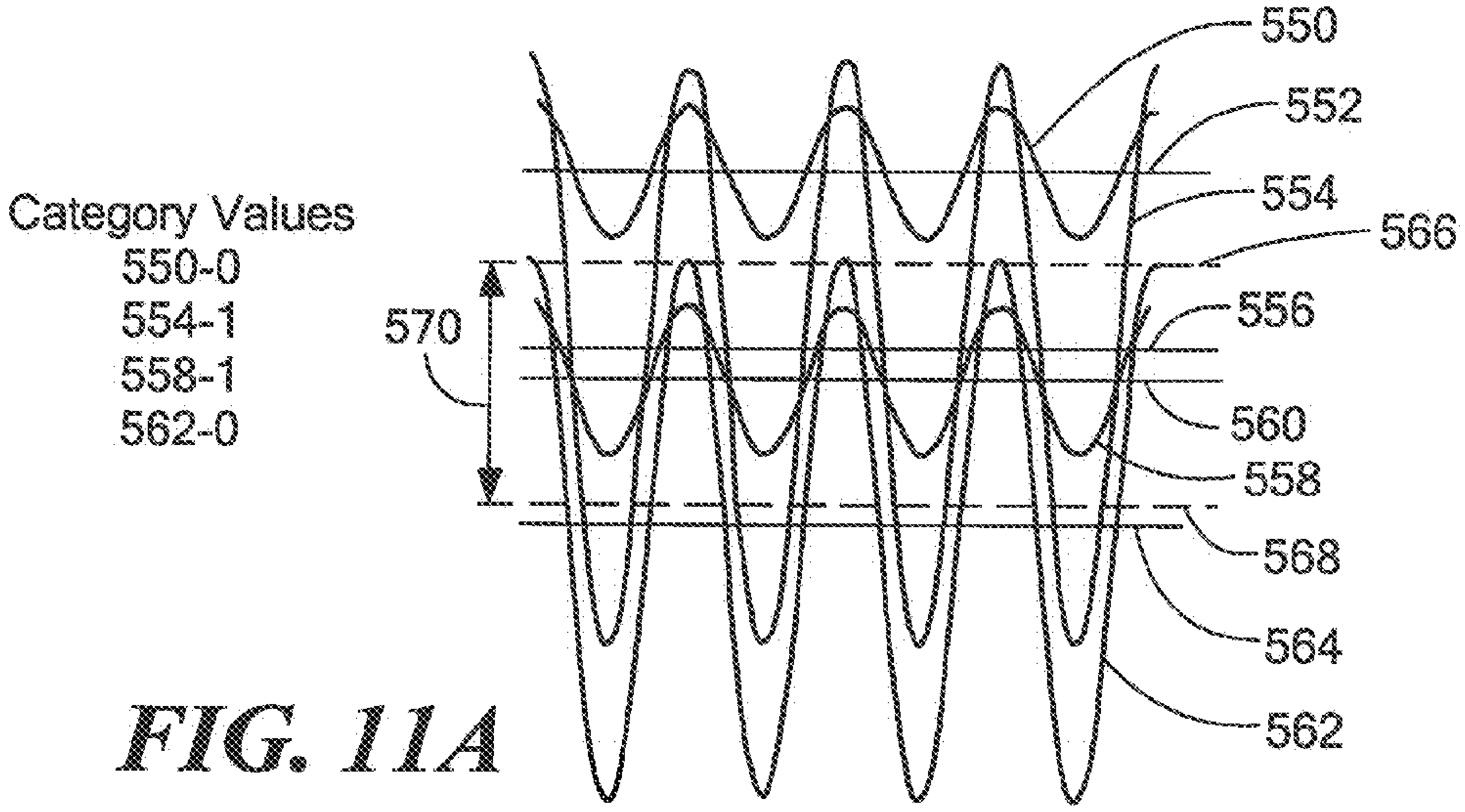

FIG. 11A

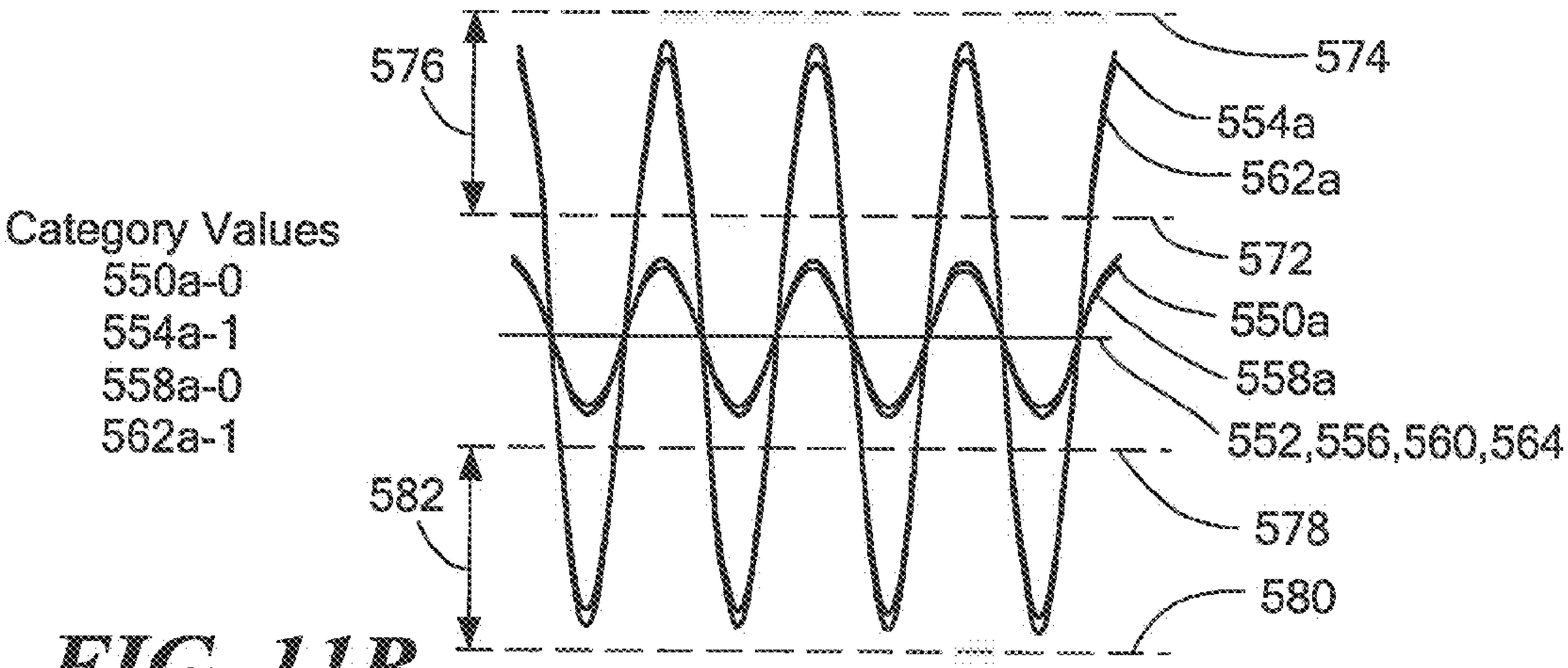

FIG. 11B

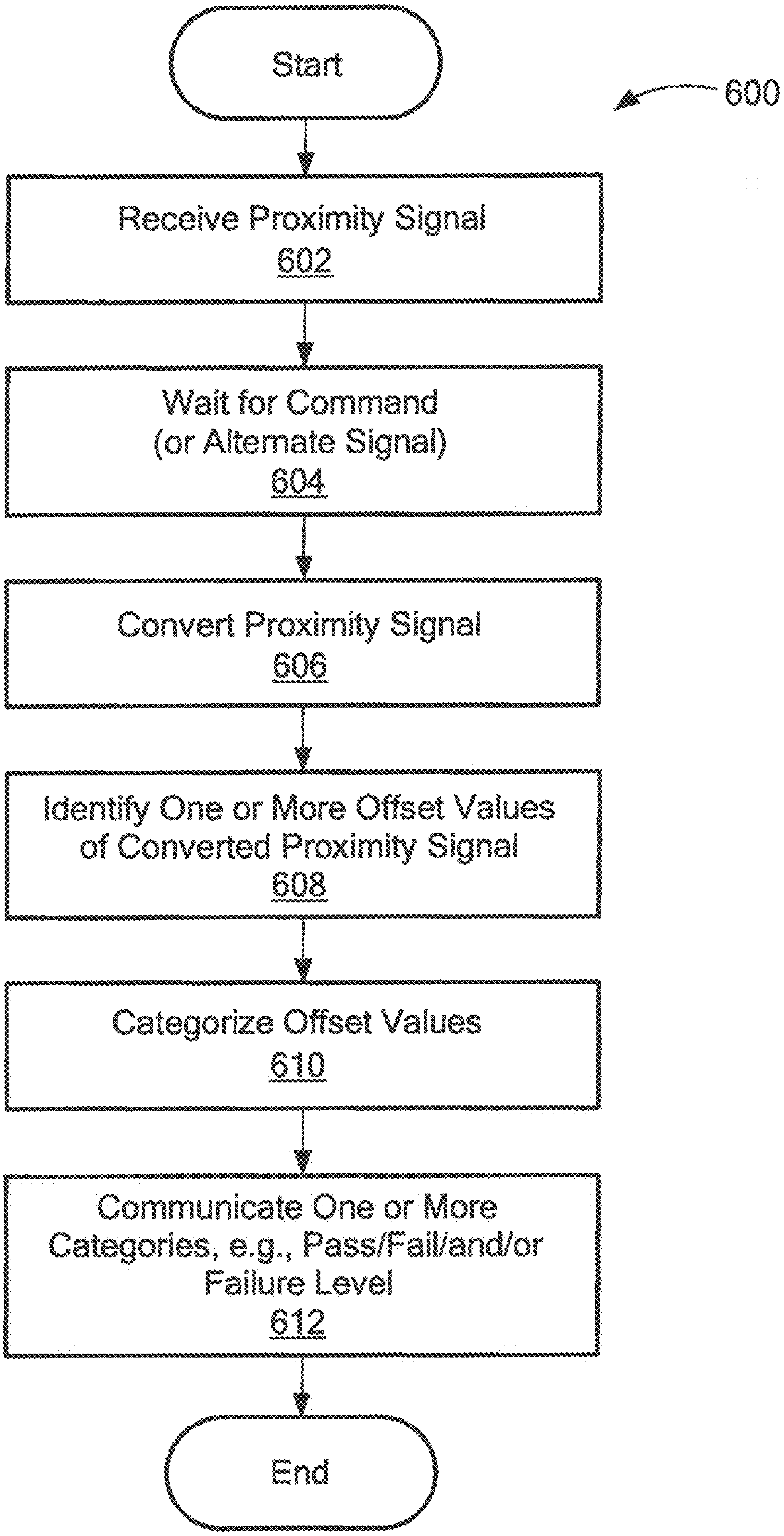
Start
600
Receive Proximity Signal
602
Wait for Command
(or Alternate Signal)
604
Convert Proximity Signal
606
Identify One or More Offset Values
of Converted Proximity Signal
608
Categorize Offset Values
610
Communicate One or More
Categories, e.g., Pass/Fail/and/or
Failure Level
612
End

FIG. 12

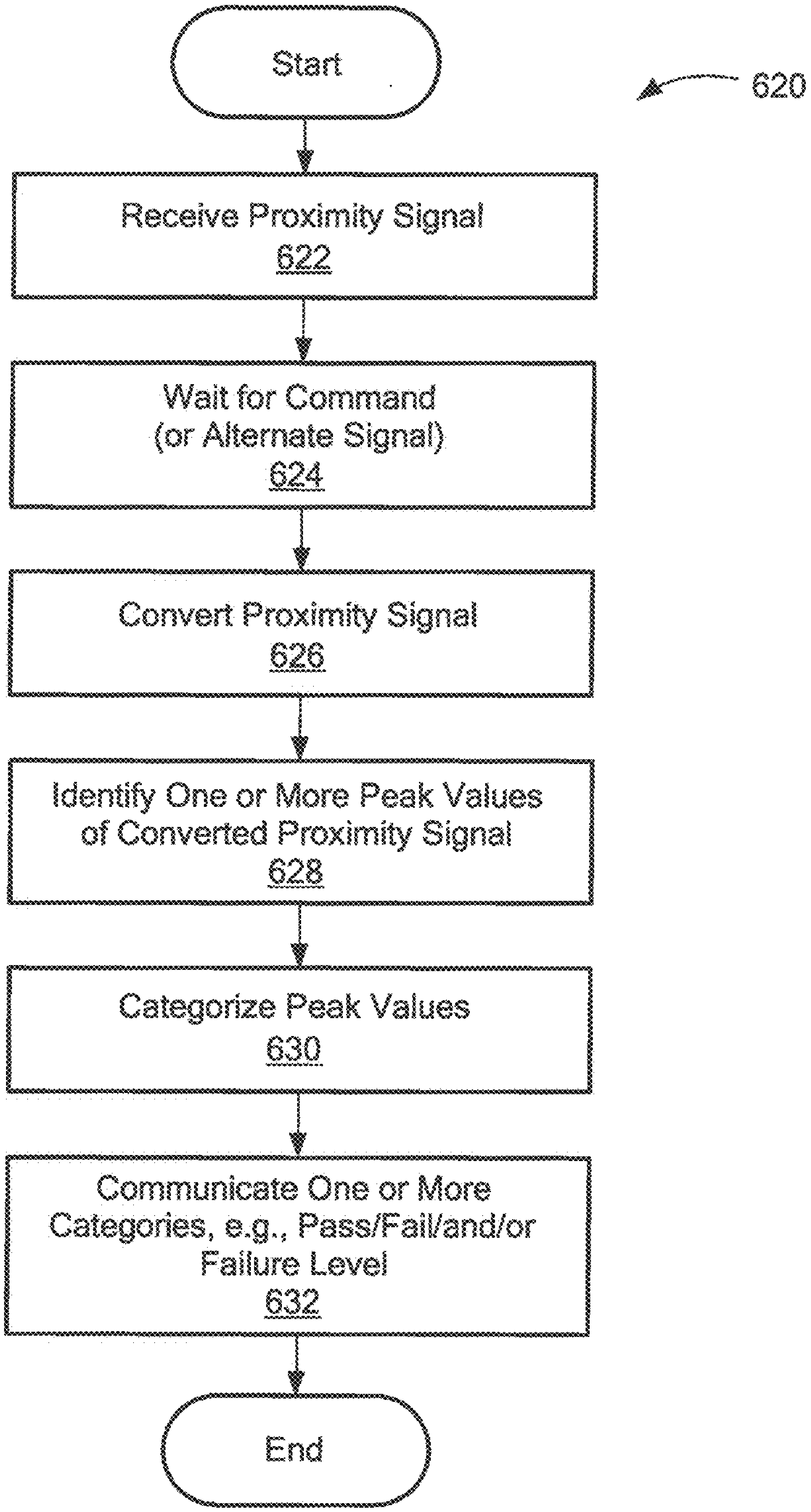
Start
620
Receive Proximity Signal
622
Wait for Command
(or Alternate Signal)
624
Convert Proximity Signal
626
Identify One or More Peak Values
of Converted Proximity Signal
628
Categorize Peak Values
630
Communicate One or More
Categories, e.g., Pass/Fail/and/or
Failure Level
632
End

FIG. 12A

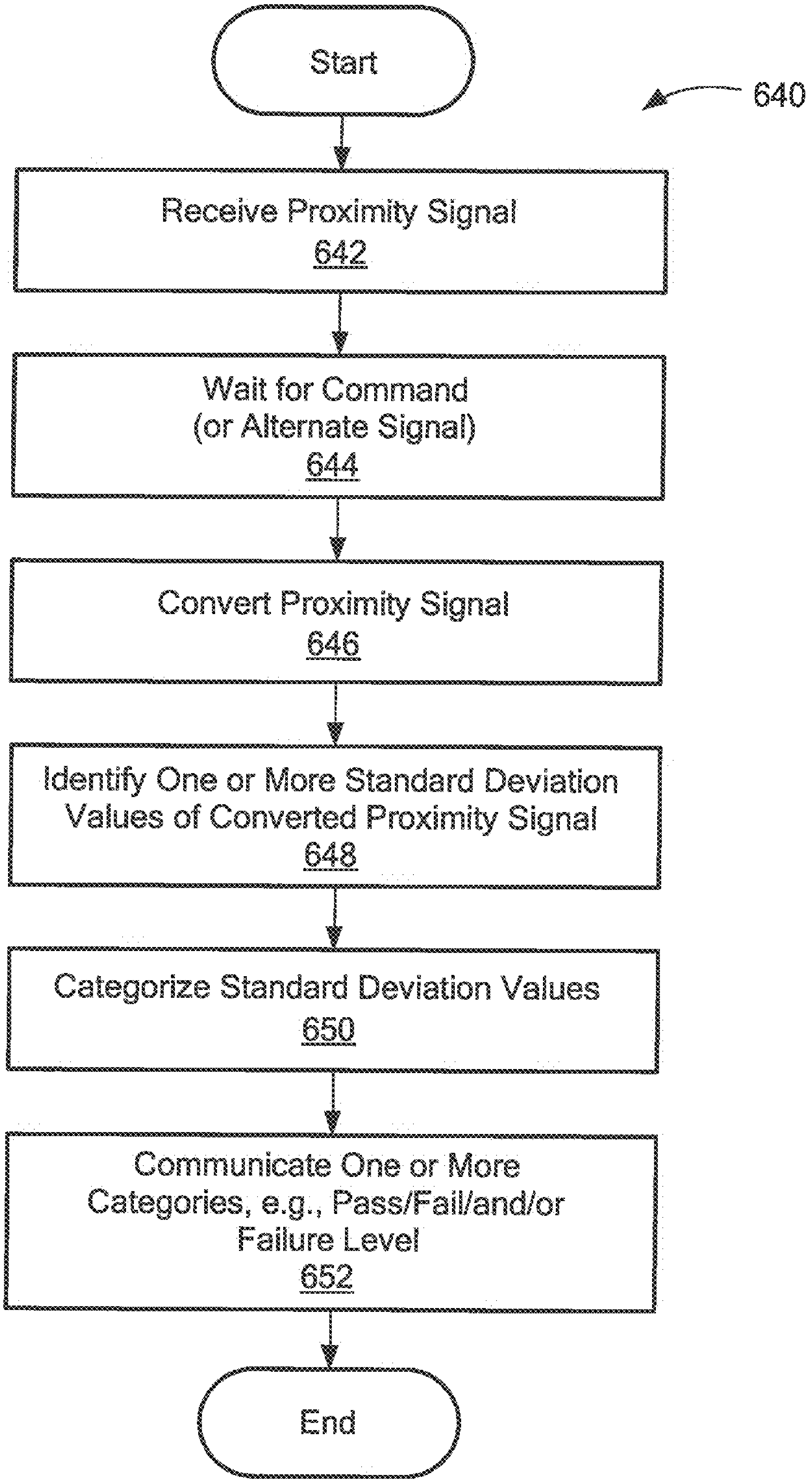
Start
640
Receive Proximity Signal
642
Wait for Command
(or Alternate Signal)
644
Convert Proximity Signal
646
Identify One or More Standard Deviation
Values of Converted Proximity Signal
648
Categorize Standard Deviation Values
650
Communicate One or More
Categories, e.g., Pass/Fail/and/or
Failure Level
652
End

FIG. 12B

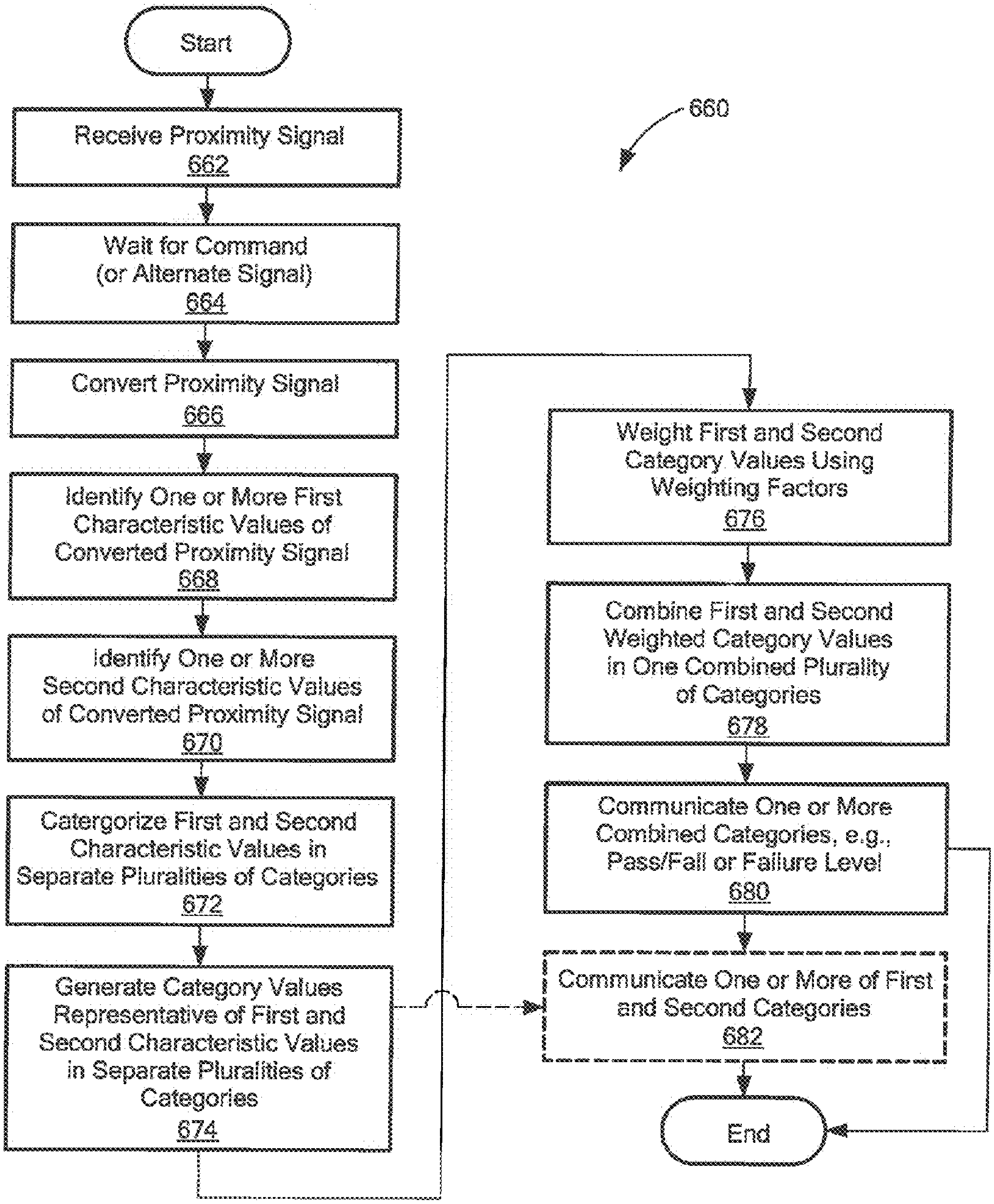
660
Start
Receive Proximity Signal
662
Wait for Command
(or Alternate Signal)
664
Convert Proximity Signal
666
Identify One or More First
Characteristic Values of
Converted Proximity Signal
668
Identify One or More
Second Characteristic Values
of Converted Proximity Signal
670
Catergorize First and Second
Characteristic Values in
Separate Pluralities of Categories
672
Generate Category Values
Representative of First and
Second Characteristic Values
in Separate Pluralities of
Categories
674
Weight First and Second
Category Values Using
Weighting Factors
676
Combine First and Second
Weighted Category Values
in One Combined Plurality
of Categories
678
Communicate One or More
Combined Categories, e.g.,
Pass/Fail or Failure Level
680
Communicate One or More of First
and Second Categories
682
End

FIG. 12C

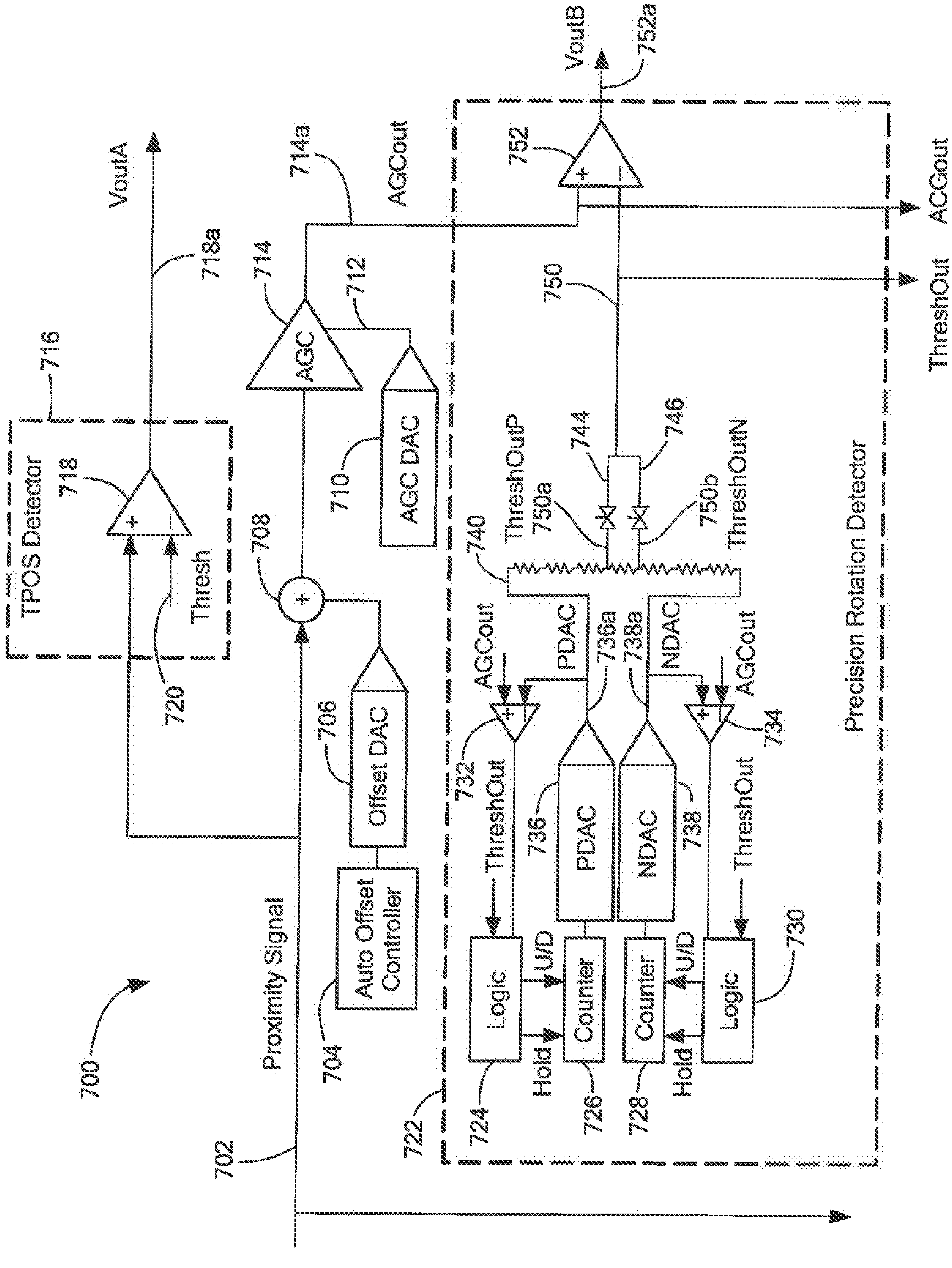
700
Proximity Signal
702
704
Auto Offset Controller
706
Offset DAC
708
710
AGC DAC
AGC
712
714
714a
AGCout
TPOS Detector
716
718
718a
720
Thresh
VoutA
722
724
Logic
Hold
U/D
726
Counter
728
Counter
730
Logic
732
734
ThreshOut
AGCout
736
PDAC
736a
738
NDAC
738a
740
ThreshOutP
ThreshOutN
744
746
750a
750b
750
752
752a
VoutB
AGCout
ThreshOut
Precision Rotation Detector

FIG. 13

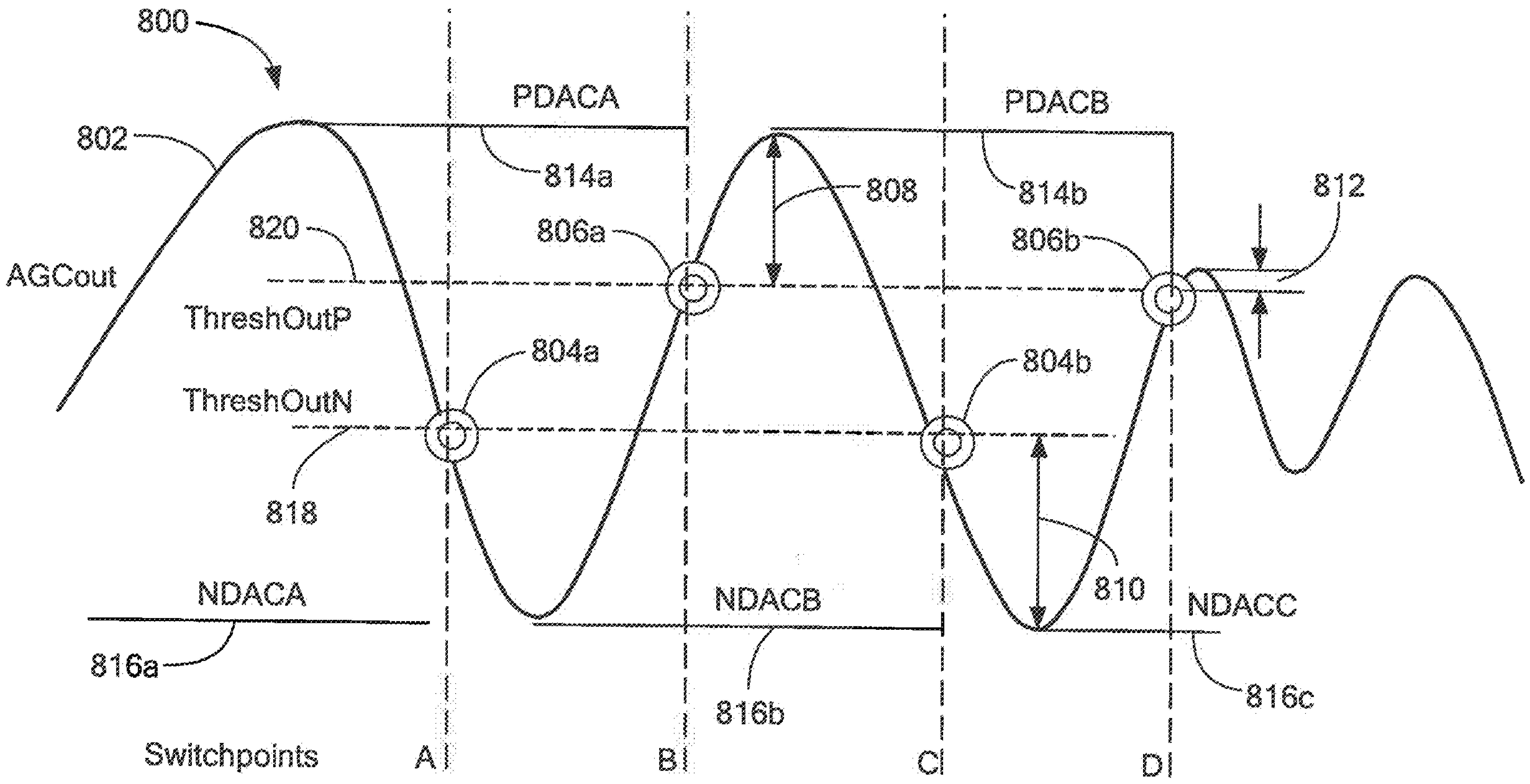
800
802
AGCout
820
ThreshOutP
ThreshOutN
818
NDACA
816a
Switchpoints
PDACA
814a
806a
804a
A
B
NDACB
816b
808
PDACB
814b
806b
804b
C
810
NDACC
816c
D
812

FIG. 14

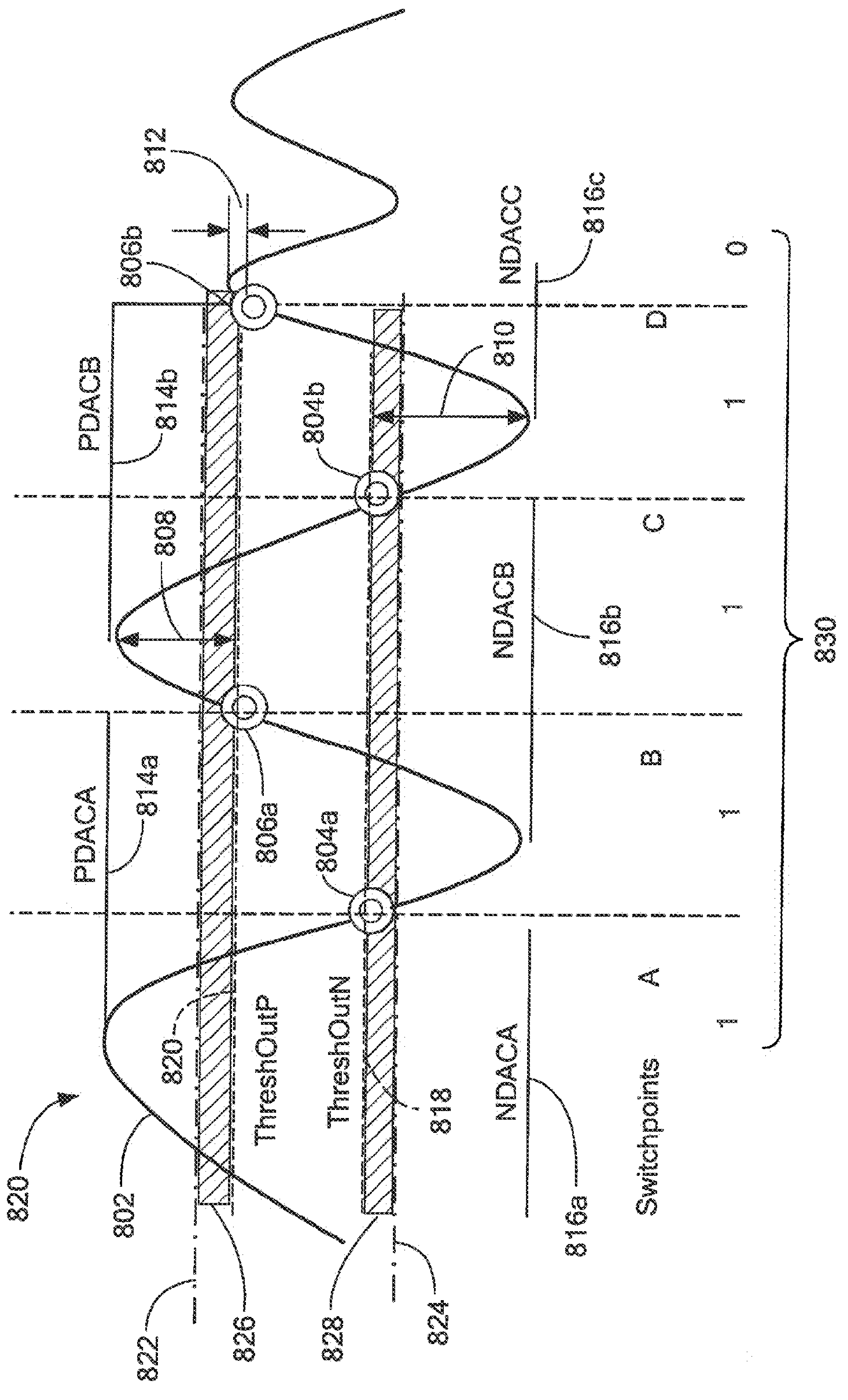
820
802
822
826
828
824
816a
Switchpoints
NDACA
818
ThreshOutN
ThreshOutP
820
PDACA
814a
804a
806a
1
A
1
B
NDACB
816b
808
PDACB
814b
804b
1
C
1
D
810
NDACC
816c
0
806b
812
830

FIG. 15

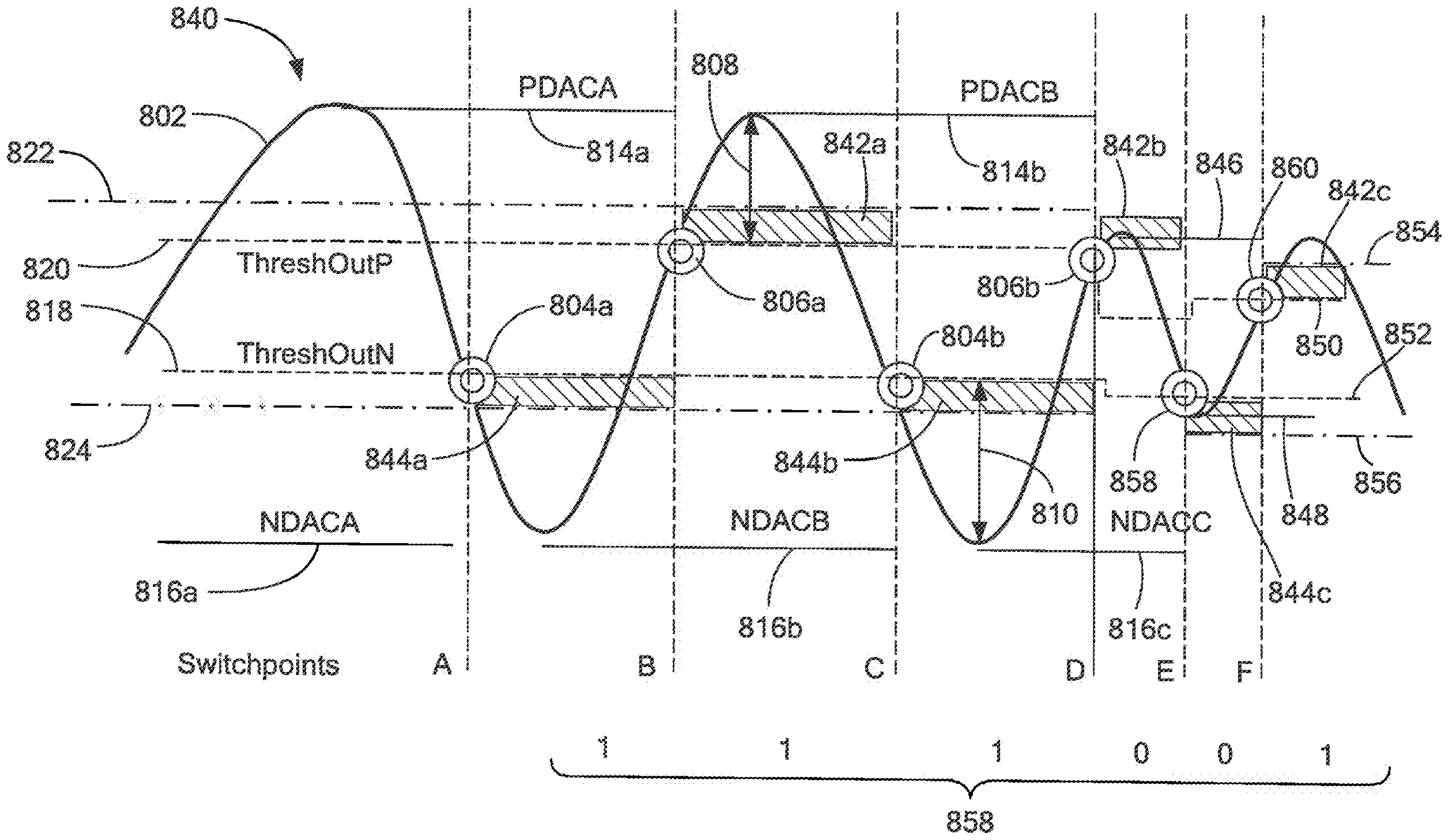
840
802
822
820
818
824
PDACA
814a
808
842a
PDACB
814b
842b
846
860
842c
854
ThreshOutP
806a
806b
850
852
804a
ThreshOutN
804b
844a
844b
810
858
856
NDACA
NDACB
NDACC
848
816a
816b
816c
844c
Switchpoints
A
B
C
D
E
F
1
1
1
0
0
1
858

FIG. 16

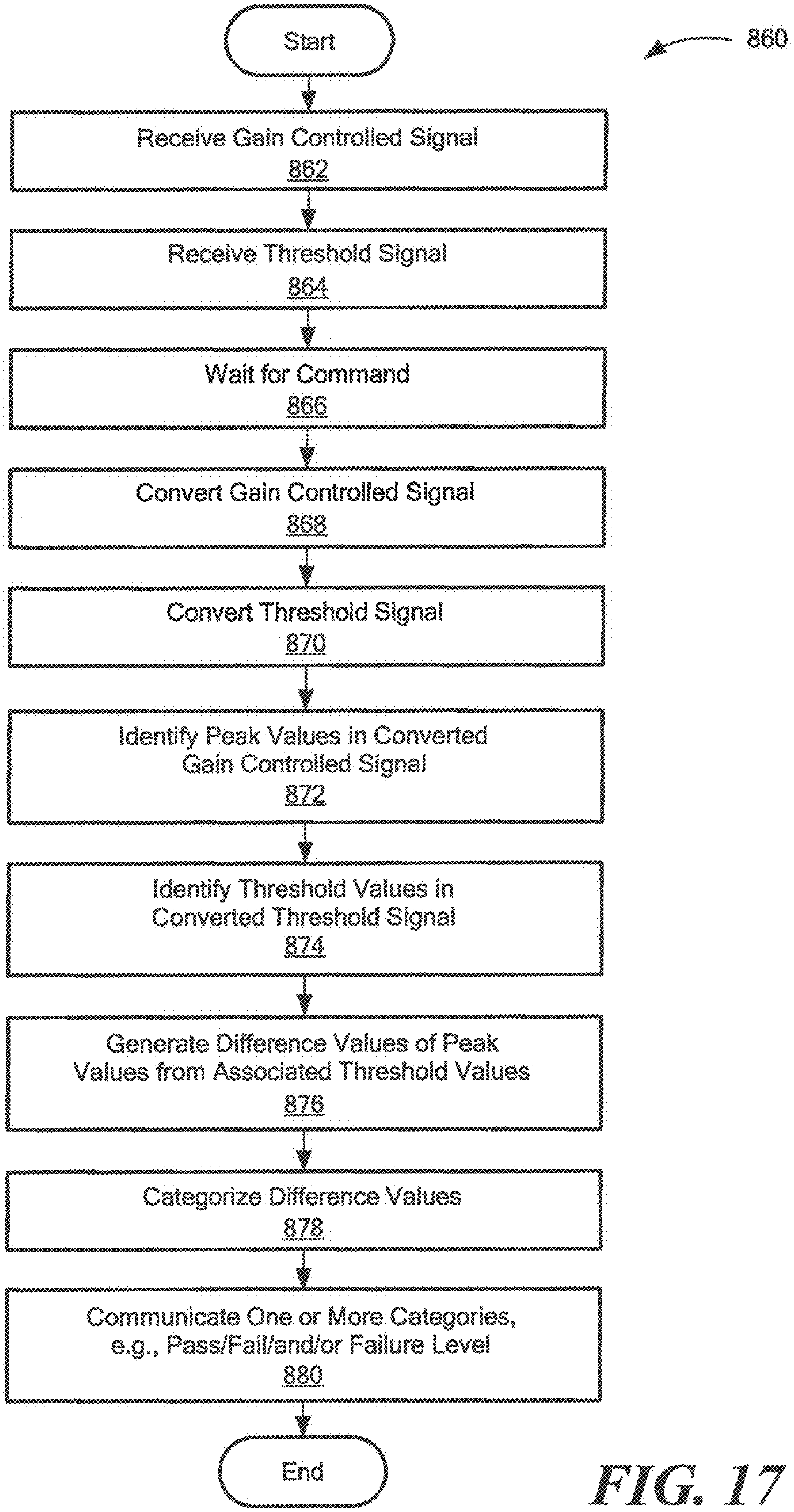
860
Start
Receive Gain Controlled Signal
862
Receive Threshold Signal
864
Wait for Command
866
Convert Gain Controlled Signal
868
Convert Threshold Signal
870
Identify Peak Values in Converted Gain Controlled Signal
872
Identify Threshold Values in Converted Threshold Signal
874
Generate Difference Values of Peak Values from Associated Threshold Values
876
Categorize Difference Values
878
Communicate One or More Categories, e.g., Pass/Fail/and/or Failure Level
880
End

FIG. 17

MAGNETIC FIELD SENSORS AND RELATED TECHNIQUES PROVIDE A SELF-TEST BY COMMUNICATING SELECTED ANALOG OR DIGITAL SAMPLES OF A PROXIMITY SIGNAL

CROSS REFERENCE TO RELATED APPLICATIONS

Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

Not Applicable.

FIELD OF THE INVENTION

This invention relates generally to magnetic field sensors and, more particularly, to a magnetic field sensor that has self-test capability and that can provide information about geometrical consistency of an object sensed by the magnetic field sensor.

BACKGROUND OF THE INVENTION

Various types of magnetic field sensing elements are known, including Hall Effect elements and magnetoresistance elements. Magnetic field sensors generally include a magnetic field sensing element and other electronic components. Some magnetic field sensors also include a fixed permanent magnet.

Magnetic field sensors provide an electrical signal representative of a sensed magnetic field. In some embodiments, the magnetic field sensor provides information about a sensed ferromagnetic object by sensing fluctuations of the magnetic field associated with the magnet part of the magnetic field sensor as an object moves within a magnetic field generated by the magnet. In the presence of a moving ferromagnetic object, the magnetic field signal sensed by the magnetic field sensor varies in accordance with a shape or profile of the moving ferromagnetic object.

In other embodiments, the magnetic field sensor has no magnet, and the magnetic field sensor provides information about a sensed object to which a magnet is coupled.

Magnetic field sensors are often used to detect movement of features of a ferromagnetic gear, such as gear teeth and/or gear slots. A magnetic field sensor in this application is commonly referred to as a "gear tooth" sensor.

In some arrangements, the gear is placed upon a target object, for example, a camshaft in an engine, thus, it is the rotation of the target object (e.g., camshaft) that is sensed by detection of the moving features of the gear. Gear tooth sensors are used, for example, in automotive applications to provide information to an engine control processor for ignition timing control, fuel management, and other operations.

In other embodiments, a ring magnet with a plurality of alternating poles, which can be ferromagnetic or otherwise magnetic, is coupled to the target object. In these embodiments, the magnetic field sensor senses rotation of the ring magnet and the target object to which it is coupled.

Information provided by the gear tooth sensor to the engine control processor can include, but is not limited to, an absolute angle of rotation of a target object (e.g., a camshaft) as it rotates, a speed of rotation, and, in some embodiments, a direction of rotation. With this information, the engine control processor can adjust the timing of firing of the ignition system and the timing of fuel injection by the fuel injection system.

Gear tooth sensors can include internal "detectors" that fall into two categories, namely, true power on state (TPOS) detectors, and precision rotation detectors. The two categories are generally distinguished by two characteristics: the speed with which they can identify edges of a gear after they are powered up, and the ultimate accuracy of their ability to detect the edges of the gear and place edges of an output signal at the proper times. TPOS sensors tend to be fast but have lower accuracy, while precision rotation detectors tend to be slower to detect a tooth or valley, but have higher accuracy.

Precision rotation detectors tend not to provide an accurate output signal (e.g., indication of tooth or valley) immediately upon movement of the target object from zero rotating speed, but instead provide an accurate output signal only once the target object has moved through at least one tooth/valley (pitch) of the target. For example, in one type of magnetic field sensor described in U.S. Pat. No. 6,525,531, issued Feb. 25, 2003, a positive digital-to-analog converter (PDAC) and a negative digital-to-analog converter (NDAC) track positive and negative peaks of magnetic field signal, respectively, for use in generating a threshold signal. A varying magnetic field signal is compared to the threshold signal. However, the outputs of the PDAC and the NDAC may not be accurate indications of the positive and negative peaks of the magnetic field signal until several cycles of the signal (i.e., signal peaks) occur (i.e., until several gear teeth have passed).

In contrast, a true power on state (TPOS) detector can provide a moderately accurate output signal state (e.g., indication of tooth or valley) before movement of a target object (e.g., camshaft) from zero rotating speed. Furthermore, even when the target object is not moving, the TPOS detector can provide an indication of whether the TPOS detector is in front of a gear tooth or a valley. The TPOS detector can be used in conjunction with a precision rotation detector in a common integrated circuit assembly, both providing information to the engine control processor at different times.

As described above, the conventional TPOS detector provides an accurate output signal before rotation of the target object and before the precision rotation detector can provide an accurate output signal. The TPOS detector can provide information to the engine control processor that can be more accurate than information provided by the precision rotation detector for time periods at the beginning of rotation of the target object, but which may be less accurate when the object is rotating at speed.

For embodiments that include both a TPOS detector and a precision rotation detector in a common integrated circuit assembly, when the object is rotating at speed, the engine control processor can primarily use rotation information provided by the precision rotation detector. In most conventional applications, once the magnetic field sensor switches to use the precision rotation detector, it does not return to use the TPOS detector until the target object stops rotating or nearly stops rotating.

A conventional TPOS detector is described in U.S. Pat. No. 7,362,094, issued Apr. 22, 2008. The conventional TPOS detector includes a comparator for comparing the magnetic field signal to a fixed, often trimmed, threshold signal. The conventional TPOS detector can be used in conjunction with and can detect rotational information about a TPOS cam (like a gear), which is disposed upon a target object, e.g., an engine camshaft, configured to rotate.

An output signal from a conventional TPOS detector has at least two states, and typically a high and a low state. The state of the conventional TPOS output signal is high when over one feature (e.g. tooth) and low when over the another feature (e.g. valley) as the target object rotates, in accordance with features on the TPOS cam attached to the target object. Similarly, the output signal from a conventional precision rotation detector has at least two states, and typically a high and a low state.

Gear tooth sensors depend upon a variety of mechanical characteristics in order to provide accuracy. For example, the gear tooth sensor must be placed close to (i.e., at a small air gap relative to) the ferromagnetic gear, teeth and valleys of which it senses as they pass. A larger air gap results in a smaller signal processed by the gear tooth sensors, which can result in noise or jitter in positions of edges of the two-state output signal generated by the gear tooth sensor. In radial sensing configurations, radial asymmetry of the ferromagnetic gear sensed by the gear tooth sensor can result in an air gap that varies as the ferromagnetic gear rotates. The radial asymmetry can take a variety of forms. For example, the radial asymmetry can result from an axis of rotation not centered in the ferromagnetic gear or from bent or missing gear teeth. In addition, wobble of the ferromagnetic gear can result in an air gap that varies. Wobble is described more fully below in conjunction with FIG. **2**.

Radial asymmetry and wobble can be the result of circumstances that happen during production of an assembly, for example an engine. Dropping an assembly during production can bend a gear sensed by the gear tooth sensor.

A gear tooth sensor can generate what appears to be a proper output signal even when exposed to a gear with radial asymmetry or with wobble. However, the gear tooth sensor can be in a marginal condition subject to failure if any further variation in the air gap occurs, for example, due to temperature changes.

Thus, it would be desirable to provide an arrangement that can sense not only a pass/fail condition, but also a marginal condition in an assembly that contains a gear tooth sensor and a sensed object (e.g. a ferromagnetic gear).

SUMMARY OF THE INVENTION

The present invention provides an arrangement that can sense not only a pass/fail condition, but also a marginal condition in an assembly that contains a gear tooth sensor and a sensed object (e.g. a ferromagnetic gear).

In accordance with one aspect of the present invention, a method of performing a self-test associated with a magnetic field sensor includes receiving a proximity signal responsive to a proximity of a sensed object with one or more magnetic field sensing elements disposed on a substrate. The method also includes identifying a plurality of values of the proximity signal, and communicating selected ones of the plurality of values.

In accordance with another aspect of the present invention, a magnetic field sensor includes a substrate and one or more magnetic field sensing elements disposed on the substrate. The one or more magnetic field sensing elements are configured to generate a proximity signal responsive to a proximity of a sensed object. The magnetic field sensor also includes a self-test module disposed on the substrate. The self-test module is coupled to receive the proximity signal, configured to identify a plurality of values of the proximity signal, and configured to communicate selected ones of the plurality of values.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features of the invention, as well as the invention itself may be more fully understood from the following detailed description of the drawings, in which:

FIG. **1** is a pictorial showing a rotating gear having gear teeth;

FIG. **1**A is a graph showing a magnetic field versus time as the gear teeth of the gear of FIG. **1** pass by a point;

FIG. **1**B is a pictorial of magnetic field sensor proximate to the gear of FIG. **1** and operable to sense the gear teeth as they pass by the magnetic field sensor;

FIG. **1**C is a graph of a so-called "proximity signal" generated by the magnetic field sensor of FIG. **1**B as the gear teeth of the gear of FIG. **1** pass by the magnetic field sensor;

FIG. **1**D is a graph of an output signal generated by the magnetic field sensor of FIG. **1**B as the gear of FIG. **1** rotates;

FIG. **2** is a pictorial showing a gear having wobble;

FIG. **2**A is a pictorial of a magnetic field sensor proximate to a gear, the gear having radial asymmetry resulting in variation of an air gap between the gear and the magnetic field sensor;

FIGS. **3**-**3**E are block diagrams showing a variety of magnetic field sensor configurations and variety of electronic circuits used within the magnetic field sensors, each electronic circuit having a self-test module;

FIG. **4** is a block diagram of a magnetic field sensor showing an expanded view of a self-test module;

FIG. **5** is a graph showing a proximity signal generated by a magnetic field sensor;

FIG. **5**A is a chart showing three groups of values representative of aspects of the proximity signal of FIG. **5**;

FIG. **6** is a flow chart showing a method of communicating the groups of values of FIG. **5**A;

FIG. **7** is a graph showing a proximity signal generated by a magnetic field sensor having two amplitudes, and also showing two amplitude thresholds;

FIG. **8** is a graph showing a proximity signal generated by a magnetic field sensor having a varying peak-to-peak amplitude;

FIG. **8**A is a graph showing the proximity signal of FIG. **8** having the varying amplitude and showing the varying peak-to-peak amplitude categorized into two discrete ranges;

FIG. **9** is a graph showing the proximity signal of FIG. **8** having the varying amplitude and showing the varying peak-to-peak amplitude categorized into four discrete ranges;

FIG. **10** is a flow chart showing a method of communicating results of a self-test associated with a magnetic field sensor;

FIG. **10**A is a flow chart showing a method of communicating results of another self-test associated with a magnetic field sensor;

FIG. **11** is a graph showing a proximity signal generated by a magnetic field sensor having a varying peak amplitude and having a varying DC offset;

FIG. **11**A is a graph representative of a way to categorize the varying DC offset of the proximity signal of FIG. **11**;

FIG. **11**B is a graph representative of a way to categorize the varying peak amplitude of the proximity signal of FIG. **11**;

FIG. **12** is a flow chart showing a method of communicating the categorized offset values of FIG. **11**A;

FIG. **12**A is a flow chart showing a method of communicating the categorized peak values of FIG. **11**B;

FIG. **12**B is a flow chart showing a method of communicating categorized deviation values of a proximity signal generated by a magnetic field sensor;

FIG. **12**C is a flow chart showing a method of weighting and combining categorized characteristic values of a signal generated by a magnetic field sensor;

FIG. **13** is a block diagram of an automatic gain control circuit, a TPOS detector, and a precision rotation detector that can be used within a magnetic field sensor;

FIG. **14** is a graph showing a gain controlled version of a proximity signal generated by a magnetic field sensor and showing thresholds used by the magnetic field sensor;

FIG. **15** is a graph showing a gain controlled version of a proximity signal generated by a magnetic field sensor, showing thresholds used by the magnetic field sensor, and showing amplitude ranges that can be used to identify self-test conditions of the magnetic field sensor;

FIG. **16** is a graph showing a gain controlled version of a proximity signal generated by a magnetic field sensor, showing thresholds used by the magnetic field sensor, and showing other amplitude ranges that can be used to identify self-test conditions of the magnetic field sensor; and

FIG. **17** is a flow chart showing a method of communicating results of yet another self-test associated with a magnetic field sensor.

DETAILED DESCRIPTION OF THE INVENTION

Before describing the present invention, some introductory concepts and terminology are explained.

As used herein, the term "magnetic field sensing element" is used to describe a variety of electronic elements that can sense a magnetic field. The magnetic field sensing element can be, but is not limited to, a Hall Effect element, a magnetoresistance element, or a magnetotransistor. As is known, there are different types of Hall Effect elements, for example, a planar Hall element, a vertical Hall element, and a Circular Vertical Hall (CVH) element. As is also known, there are different types of magnetoresistance elements, for example, a semiconductor magnetoresistance element such as Indium Antimonide (InSb), a giant magnetoresistance (GMR) element, an anisotropic magnetoresistance element (AMR), a tunneling magnetoresistance (TMR) element, and a magnetic tunnel junction (MTJ). The magnetic field sensing element may be a single element or, alternatively, may include two or more elements arranged in various configurations, e.g., a half bridge or full (Wheatstone) bridge. Depending on the device type and other application requirements, the sensing element XX may be a device made of a type IV semiconductor material such as Silicon (Si) or Germanium (Ge), or a type III-V semiconductor material like Gallium-Arsenide (GaAs) or an Indium compound, e.g., Indium-Antimonide (InSb).

A so-called "circular vertical Hall" (CVH) sensing element, which includes a plurality of vertical magnetic field sensing elements, is known and described in PCT Patent Application No. PCT/EP2008/056517, entitled "Magnetic Field Sensor for Measuring Direction of a Magnetic Field in a Plane," filed May 28, 2008, and published in the English language as PCT Publication No. WO 2008/145662, which application and publication thereof are incorporated by reference herein in their entirety. The CVH sensing element includes a circular arrangement of vertical Hall elements arranged over a common circular implant region in a substrate. The CVH sensing element can be used to sense a direction (and optionally a strength) of a magnetic field in a plane of the substrate.

As is known, some of the above-described magnetic field sensing elements tend to have an axis of maximum sensitivity parallel to a substrate that supports the magnetic field sensing element, and others of the above-described magnetic field sensing elements tend to have an axis of maximum sensitivity perpendicular to a substrate that supports the magnetic field sensing element. In particular, planar Hall elements and semiconductor magnetoresistance elements tend to have axes of sensitivity perpendicular to a substrate, while AMR, GMR, and TMR types of magnetoresistance elements and vertical Hall elements (including circular vertical Hall (CVH) sensing elements) tend to have axes of sensitivity parallel to a substrate.

As used herein, the term "magnetic field sensor" is used to describe a circuit that includes a magnetic field sensing element. Magnetic field sensors are used in a variety of applications, including, but not limited to, a current sensor that senses a magnetic field generated by a current carried by a current-carrying conductor, a magnetic switch that senses the proximity of a ferromagnetic object, a rotation detector (true power on state (TPOS) detector and precision rotation detector) that senses passing ferromagnetic articles, for example, magnetic domains of a ring magnet, and a magnetic field sensor that senses a magnetic field density of a magnetic field.

As used herein, the term "accuracy," when referring to a magnetic field sensor, is used to refer to a variety of aspects of the magnetic field sensor. These aspects include, but are not limited to, an ability of the magnetic field sensor to differentiate: a gear tooth from a gear valley (or, more generally, the presence of a ferromagnetic object from the absence of a ferromagnetic object) when the gear is not rotating and/or when the gear is rotating (or, more generally, when a ferromagnetic object is moving or not moving), an ability to identify an edge of a tooth of the gear from the tooth or the valley of the gear (or, more generally, the edge of a ferromagnetic object), and a rotational accuracy with which the edge of the gear tooth is identified (or, more generally, the positional accuracy with which an edge of a ferromagnetic object can be identified), i.e., output signal edge placement accuracy and consistency with respect to gear tooth edges passing by the magnetic field sensor.

It is desirable for magnetic field sensors to achieve accuracy even in the presence of variations in an air gap between the magnetic field sensor and the gear that may change from installation to installation or from time to time. It is also desirable for magnetic field sensors to achieve accuracy even in the presence of variations in relative positions of the magnet and the magnetic field sensing element within the magnetic field sensor. It is also desirable for magnetic field sensors to achieve accuracy even in the presence of unit-to-unit variations in the magnetic field generated by a magnet within the magnetic field sensors. It is also desirable for magnetic field sensors to achieve accuracy even in the presence of variations of an axial rotation of the magnetic field sensors relative to the gear. It is also desirable for magnetic field sensors to achieve accuracy even in the presence of temperature variations of the magnetic field sensors. It is also desirable for magnetic field sensors to achieve accuracy even in the presence of wobble and/or radial asymmetry of a gear sensed by the magnetic field sensors.

Examples below describe a particular gear as may be used upon an engine camshaft target object. However, similar circuits and techniques can be used with other cams or gears disposed upon the engine camshaft, or upon other rotating parts of a vehicle (e.g., crank shaft, transmission gear, anti-lock braking system (ABS)), or upon rotating parts of a device that is not an automotive grade vehicle (e.g. tractors, golf carts, etc). The gear is not a part of the magnetic field sensor described below. The gear can have ferromagnetic gear teeth.

Examples shown below show a so-called "back-biased" arrangement, in which a permanent magnet, disposed within an integrated circuit package (or alternatively, outside of the magnetic field sensor package), provides a magnet field, which is modulated by passing ferromagnetic gear teeth.

In other embodiments, there is can be no back biasing magnet, and instead, the magnetic field sensor can sense a changing magnetic field generated by a moving permanent magnet, for example, a ring magnet having alternating north and south poles, i.e., magnetic features.

Also, while examples are shown below of magnetic field sensors that can sense ferromagnetic gear teeth upon a gear configured to rotate, the magnetic field sensors can be used in other applications. The other applications include, but are not limited to, sensing ferromagnetic objects, for example, soft ferromagnetic objects (with a back-biased arrangement) or hard ferromagnetic objects (i.e., permanent magnets) or magnetic objects upon a linear structure configured to move linearly.

As used herein, the term “characteristic value” is used to describe a characteristic of an electrical signal, either a continuous analog signal, a sampled analog signal, or a digital signal. Examples are given below of characteristic values, including, peak-to-peak values, peak values (i.e., zero-to-peak values), DC values (e.g., mean values), and deviation values (e.g., standard deviation values. However, it should be understood that other characteristic values can be used.

As used herein, the term “self-test” is used with reference to a magnetic field sensor configured to sense a movement of an object. The term “self-test” is used to describe functions of the magnetic field sensor that can sense, i.e., test, not only proper or improper operation of the magnetic field sensor itself, but also proper or improper magnetic fields sensed by the magnetic field sensor as may relate to proper or improper characteristics of the sensed object. For example, where the sensed object is a gear, the self-test can identify proper or improper aspects (e.g., rotation) of the gear, as may be indicative, for example, of a wobble of the gear, a bent gear tooth, or a radial asymmetry of the gear.

As used herein, it should be understood that the term “ferromagnetic object” includes objects comprised of at least one of a soft magnetic material or a hard magnetic material. The term “soft magnetic material” is used herein to refer to a material (e.g., non-magnetized iron or ferrite) that is influenced by a magnetic field but that tends not to generate a magnetic field. In contrast, the term “hard magnetic material” is used herein to refer to a material that generates a magnetic field (i.e., a magnet). With regard to materials that generate a magnetic field, it will be understood that some non-ferrous materials (e.g., rare earth materials) can generate a magnetic field. It is intended that the term “ferromagnetic” encompass those materials as well.

While signals having particular states (e.g., high, low, mid) are shown in examples below, it should be understood that the states can be different states. For examples, a high state can be interchanged with a low state, and a mid state can be interchanged with a high or a low state.

Relative and absolute sizes and scales represented in figures below are sizes and scales selected for clarity and do not necessarily represent true sizes and scales.

Referring now to FIG. **1**, a ferromagnetic gear **10** can be sensed by a magnetic field sensor **14**. More particularly, gear teeth, e.g., **10***a*, and valleys, e.g., **10***b*, can be sensed by the magnetic field sensor **14** as the gear **10** rotates, for example, in a direction **12**.

In some other embodiments, the gear is instead a magnetic object, for example, a ring magnet having a plurality of magnetic regions with opposing magnetic field directions.

Referring now to FIG. **1**A, a magnetic flux density curve **20** has peaks, e.g., **20***a*, and valleys, e.g., **20***b*, associated with gear teeth and valleys upon the gear **10** of FIG. **1** when the ferromagnetic gear **10** of FIG. **1** is exposed to a static DC magnetic field.

Referring now to FIG. **1**B, a magnetic field sensor **40** can be the same as or similar to the magnetic field sensor **14** of FIG. **1** and can experience the changing magnetic field **20** of FIG. **1**A as the gear **10** of FIG. **1** rotates.

The magnetic field sensor **40** can include a substrate **42** upon which, for example, two magnetic field sensing elements **44**, **46** can be disposed, which can be separated by a distance **48** in a direction perpendicular to a radius of the gear **10** of FIG. **1**. And electronic circuit **50** coupled to the two magnetic field sensing elements **44**, **46** can also be disposed upon the substrate. A permanent magnet **52** can be disposed proximate to the substrate **42** and can generate a magnetic field that is modulated by the teeth and valleys of the gear **10** of FIG. **1** as the gear **10** rotates.

The magnetic field sensor **40** can include an encapsulation **54** surrounding the substrate **42** and the magnet **52**.

The magnetic field sensing elements **44**, **46** and the electronic circuit **50** are described in more detail below in conjunction with FIGS. **3**-**3**E. Let it suffice here to say that the two magnetic field sensing elements **44**, **46** generate analog proximity signals that vary in relation to the magnetic field **20** of FIG. **1**A as the gear **10** of FIG. **1** rotates. In some embodiments, two proximity signals generated by the two magnetic sensing elements **44**, **46** are combined (e.g., subtracted) so as to form one proximity signal. The proximity signals, or the one proximity signal, are received and processed by the electronic circuit **50** to generate a two state output signal.

Referring now to FIG. **1**C, a signal **60** is representative of the proximity signal resulting from combining two proximity signals generated by the two magnetic field sensing elements **44**, **46** of FIG. **1**B. Operating point thresholds, BOP(#**1**) and BOP(#**2**), are shown. Release point thresholds, BRP(#**1**) and BRP(#**2**), are also shown. The electronic circuit **50** of FIG. **1**B can be operable to generate the operating point and release point thresholds in a variety of ways described more fully below in conjunction with FIG. **13**. In some embodiments, new operating and release point threshold are generated upon each cycle of the proximity signal **60**. The proximity signal **60** can be compared with the operating point and release point thresholds.

Referring now to FIG. **1**D, a signal **80** is representative of an output signal generated by the magnetic field sensor **40** of FIG. **1**B as the gear **10** of FIG. **1** rotates. Edges of the signal **80** occur as the proximity signal **60** of FIG. **1**C crosses operating point and release point thresholds a shown.

It should be understood that a frequency of the signal **80** is representative of a rotational speed of the gear **10** or FIG. **1**. It should also be understood that positions of edges of the signal **80** are representative of positions of edges of the gear teeth of the gear **10** of FIG. **1**. It is desirable that the edges of the signal **80** accurately represent positions of the gear teeth of the gear **10** of FIG. **1**, without noise and without jitter.

Referring now to FIG. **2**, a magnetic field sensor **100** is disposed proximate to a gear **102** configured to rotate. The magnetic field sensor **100** can be the same as or similar to the magnetic field sensor **40** of FIG. **1**B.

As described above, the gear **102** can experience wobble, resulting in the gear **102** or parts of the gear **102**, being at a position **102***a* at some parts of rotation of the gear **102** and at a position **102***b* at other parts of the rotation of the gear **102**. The wobble can be characterized by a radial axis **104** of the gear **102** changing between positions **106***a* and **106***b* over a range of positions **108** as the gear **102** rotates.

It should be understood that, in the presence of the gear **102** that wobbles, an air gap between the magnetic field sensor **100** and the gear **102** changes as the gear **102** rotates. The changing air gap results in a changing magnitude of an analog proximity signal generated by magnetic field sensing elements within the magnetic field sensor **100** and a resulting loss of accuracy of the magnetic field sensor.

The wobble may be large enough so that an output signal (two-state signal) generated by the magnetic field sensor has gross irregularities in edge placements. However, the wobble may also be of a smaller magnitude resulting in no (or a small) effect upon the output signal. Still, if the air gap were to change further, for example, due to temperature, the output signal generated by the magnetic field sensor may degrade further. Thus, this condition may be deemed to be a marginal condition.

Referring now to FIG. **2**A, a magnetic field sensor **122**, here shown with three different air gaps **122***a*, **122***b*, **122***c* relative to a gear **120** (i.e., at air gaps of 1×, 4×, and 8×), has a corresponding three different magnitudes (1×, 0.25×, and 0.15×) of analog proximity signals generated by magnetic field sensing elements (not shown) within the magnetic field sensor **122***a*, **122***b*, **122***c* as the gear **120** rotates. The relationship tends to be non-linear.

The three different air gaps can be representative of a continuous change in air gap as the gear **120** rotates, due to radial asymmetry of the gear **120**, for example, resulting from an axis of rotation not geometrically centered on the gear.

Both the wobble of FIG. **2** and the radial asymmetry represented by FIG. **2**A can result from damage of the gear during production. The wobble and radial asymmetry can also result from wear of the gear and axis upon which the gear rotates during operation of the assembly in which the gear is used.

Referring to FIG. **3**, an exemplary magnetic field sensor **140** is responsive to a gear **152** having ferromagnetic gear teeth, e.g., gear teeth **152***a*, **152***b*, **152***c*. The magnetic field sensor **140** includes a magnetic field sensing element **142** coupled to an electronic circuit **146**. The magnetic field sensing element **142** and the electronic circuit **146** can be disposed upon (i.e., integrated within or upon) a substrate **144**. Here, the magnetic field sensing element **142** is shown to be a Hall element with an exaggerated size for clarity. As is known, a Hall element can be integrated within the substrate **144**.

The magnetic field sensor **140** can also include a magnet **148**. The magnet **148** is configured to generate a magnetic field, which is generally directed along an axis **154** at the position of the magnetic field sensing element **142**, and which is subject to direction and amplitude changes depending upon positions of the gear teeth **152***a*, **152***b*, **152***c* relative to the magnetic field sensor **140**.

The electronic circuit **148** is configured to generate an output signal (not shown), which can be the same as or similar to the signal **80** of FIG. **1**D. The output signal, when the gear is not moving, has a state indicative of whether the magnetic field sensor **140** is over a gear tooth or a gear valley. The output signal, when the gear is rotating, has an edge rate or a frequency indicative of a speed of rotation of the gear. Edges or transitions of states of the output signal can be used to identify positions of edges of the gear teeth as they pass by the magnetic field sensor.

The magnet **148** can include a central core **150** disposed within the magnet **148**. An exemplary magnet with a core is described in U.S. Pat. No. 6,278,269, entitled "Magnet Structure," issued Aug. 21, 2001, which patent is assigned to the assignee of the present invention and incorporated herein by reference in its entirety. As described in U.S. Pat. No. 6,278,269, the pole configuration provided by the magnet **148** with the core **150** lowers the base field (or baseline) of a flux density map of the magnetic field by bringing both poles of the magnetic field to a surface of the magnet proximate to the substrate **144**. A predetermined baseline (e.g., within a range of about +/−six hundred Gauss) at the magnetic field sensing element **142**, and a resulting differential magnetic field signal **142***a*, **142***b* (i.e., an analog differential proximity signal) near zero, can be achieved with proper design.

In contrast, when a gear tooth is proximate to the magnetic field sensing element **142**, the magnetic field sensing element **142** experiences a higher magnetic field and generates the differential proximity signal **142***a*, **142***b* with a high value.

As is apparent, the baseline remains constant and close to zero even as the air gap between the gear teeth and the magnetic field sensor **140** varies. This advantageous result of low baseline substantially independent of air gap is achieved by presenting opposite poles at the face of the magnet **148** and core **150** proximate to the magnetic field sensing element. This effect is also described in U.S. Pat. No. 5,781,005, issued Jul. 14, 1998, entitled "Hall-Effect Ferromagnetic-Article-Proximity Sensor," which patent is assigned to the assignee of the present invention and incorporated herein by reference in its entirety.

The above-described low baseline results in an enhanced ability of the electronic circuit **146** to differentiate the presence of the gear tooth from a gear valley. Thus, the magnetic field sensor **140** can be referred to as a "tooth detector," as opposed to "edge detectors" described below.

The magnetic field described above and provided by the magnet **148** with the core **150** results in an improved accuracy of the magnetic field sensor **140**. For example, the improved magnetic field allows the magnetic field sensing element **142** to be somewhat statically misaligned from a center of the magnet **148**, as will occur due to unit-to-unit variations of mechanical alignments, without sacrificing accuracy of the magnetic field sensor **140**. Accuracy is discussed above.

However, the analog differential proximity signal **142***a*, **142***b* generated by the magnetic field sensing element **140** still tend to vary in the presence of wobble or radial asymmetry of the gear **152**. The wobble or radial asymmetry of the gear **152** can result in a complete inability (i.e., complete failure) of the magnetic field sensor **140** to accurately sense positions of the gear teeth. It will be understood that a complete failure may be more easily detected than a marginally functioning magnetic field sensor. Detections of marginal conditions are described more fully below.

Referring now to FIG. **3**A, an exemplary electronic circuit **160** can be the same as or similar to electronic circuit **146** of FIG. **3**. The electronic circuit **160** can include an amplifier **164** coupled to receive a differential proximity signal **162***a*, **162***b*, which can be the same as or similar to the differential proximity signal **142***a*, **142***b* generated by the magnetic field sensing element **142** of FIG. **3**. The amplifier **164** is configured to generate an amplified signal **164***a* (also a proximity signal), which, in some embodiments, can split into two channels.

In a true power on state (TPOS) channel, a TPOS detector **166** can be coupled to receive the amplified signal **164***a* and configured to generate a TPOS output signal **166***a*. To this end, in some embodiments, the TPOS detector **166** can include a comparator (not shown) configured to compare the amplified signal **166***a* with a fixed predetermined (and trimmed) threshold. In these embodiments, the TPOS output signal **166***a* can be a two-state binary signal for which a high state is indicative of a gear tooth being proximate to the magnetic field sensor **140** of FIG. **3** and a low state is indicative of a gear valley being proximate to the magnetic field sensor **140**, or vice versa.

In a precision rotation detector channel, an automatic gain control (AGC) **168** can be coupled to receive the amplified proximity signal **164***a* and configured to generate a gain controlled signal **168***a*. A precision rotation detector **170** can be coupled to receive the gain controlled signal **168***a* and configured to generate a precision rotation detector output signal **170***a*. Like the TPOS output signal **166***a*, the precision rotation detector output signal **170***a* can be a two-state binary signal for which a high state is indicative of a gear tooth being proximate to the magnetic field sensor **140** of FIG. **3** and a low state is indicative of a gear valley being proximate to the magnetic field sensor **140**, or vice versa. Thus, both the TPOS detector **166** and the precision rotation detector **170** can be "tooth detectors."

In some alternate embodiments, the precision rotation detector **170** can be an "edge detector," which is unable to identify whether the magnetic field sensor **142** is proximate to a gear tooth or a gear valley, particularly when the gear is not moving. However, a low to high state transition of the precision rotation detector output signal **170***a* can be indicative of a transition from a gear valley being proximate to the magnetic field sensing element **142** to a gear tooth being proximate to the magnetic field sensing element **142**, and a high to low state transition can be indicative of a transition from the gear tooth being proximate to the magnetic field sensing element **142** to a gear valley thing proximate to the magnetic field sensing element **142**, or vice versa.

The precision rotation detector **170** can be coupled to, or can otherwise include, a calibration/running mode control module **171**. The calibration/running mode control module **171** can be operable to cause the precision rotation detector **170** to use first thresholds for comparison with the gain controlled signal **168***a* during a "calibration mode," usually for a short time period following a beginning of rotation of the gear that is being sensed. Thereafter, the calibration/running mode control module **171** can be operable to cause the precision rotation detector **170** to use second different thresholds accurately determined by the precision rotation detector **170** during a "running mode."

Precision rotation detectors, e.g., the precision rotation detector **170**, can have a variety of configurations. Some configurations are described in the above mentioned U.S. Pat. No. 6,525,531. However, other forms of precision rotation detectors are also known. An exemplary precision rotation detector and an exemplary TPOS detector are described in greater detail below in conjunction with FIG. **13**.

In general, from discussion above, it will be appreciated that the TPOS output signal **166***a* is able to identify whether the magnetic field sensing element **142** is proximate to a gear tooth or to a gear valley, even when the gear, e.g., the gear **152** of FIG. **3** is stationary. However, since the TPOS detector **166** uses a fixed threshold, variations in the edge placement in the TPOS output signal **166***a* will occur due to a variety of factors, including, but not limited to, temperature variations, and variations in the air gap between the magnetic field sensing element **142** and the gear **152**.

Unlike the TPOS detector **166**, which uses fixed thresholds, the precision rotation detector **170** continually makes adjustments of thresholds to provide the precision rotation detector output signal **170***a* with better accuracy of edge placements of the precision rotation detector output signal **170***a* relative to physical positions of gear teeth, and edges of gear teeth in particular.

A multiplexer **174** can be coupled to receive the TPOS output signal **166***a* and coupled to receive the precision rotation detector output signal **170***a*. Select logic **172** can provide a selection signal **172***a*, received by the multiplexer/output module **174**. Depending upon the state of the selection signal **172***a*, the multiplexer **174** is configured to generate a signal **174***a* representative of a selected one of the TPOS output signal **166***a* or the precision rotation detector output signal **170***a*.

The signal **174***a* is representative of rotation of the gear **152** of FIG. **3**, and thus, is also referred to herein as a "rotation signal." In some embodiments, the rotation signal has a first state associated with a gear tooth and a second different state associated with a valley in the gear **152**.

The select logic **172** can be coupled to receive the TPOS output signal **166***a*. In some exemplary embodiments, the select logic **172** selects the signal **174***a* to be representative of the TPOS output signal **166***a* for a predetermined amount of time after the gear **152** starts rotating as indicated by the TPOS output signal **166***a*. Thereafter, the select logic **172** selects the signal **174***a* to be representative of the precision rotation detector output signal **170***a*.

Other magnetic field sensors can include only the TPOS channel having the TPOS detector **166** or only the precision rotation detector channel having the precision rotation detector **170**.

An output format module **176** can be coupled to receive the signal **174***a* and configured to generate a signal **176***a*, which can be an output part of a bidirectional signal **176***a*. A received part of the bidirectional signal **176***a* can be a command signal described more fully below.

The signal **176***a* can be provided in a variety of signal formats, including, but not limited to, a SENT format, an I2C format, a PWM format, a three-state format, or a two-state format native to the TPOS output signal **166***a* and to the precision rotation detector output signal **170***a*.

The electronic circuit **160** can also include a self-test module **178**. The self-test module **178** can be coupled to receive the amplified (proximity) signal **164***a*. In some embodiments, the self-test module **178** is also coupled to receive a signal **170***b* from the precision rotation detector **170**. The signal **170***b* can be representative of a threshold signal generated within the precision rotation detector **170**. In some embodiments, the self-test module **178** is also coupled to receive a control signal **171***a* from the calibration/running mode control module **171**, which is indicative of whether the precision rotation detector **170** is in the calibration mode or in the running mode following the calibration mode. In some embodiments, the self-test module **178** is also coupled to receive the gain controlled signal **164***a*.

The self-test module **178** is configured to generate a self-test signal **178***a*. In some embodiments, the self-test signal **178***a* is a multi-bit digital signal representative of an analog-to-digital conversion of all of, or parts of, the amplified proximity signal **164***a*. In some other embodiments, the self-test signal **178***a* is a two-state signal representative of a passing condition or a failing condition of the magnetic field sensor **160**. In still other embodiments, the self-test signal **178***a* is a signal having more than two states representative of more than two self-test conditions of the magnetic field sensor **160**, for example, a passing condition, a failing condition, and one or more marginal conditions.

The output format module **176** can be coupled to receive the self-test signal **178***a*. In some embodiments, the output format module **176** is configured to provide as an output part of the bidirectional signal **176***a*, either the rotation signal **174***a* (indicative of rotation of the gear **152**) or the self-test signal **178***a* (representative of a self-test condition of the magnetic field sensor **140** or of the gear **152** of FIG. **3**), as selected by a command signal received as a command part of the bidirectional signal **176***a*. To this end the self-test module **178** can be coupled to receive a command signal **176***b* from the output format module **176**, which can command the self-test module **178** to perform one or more self-test functions associated with the self-test signal **178***a*.

The magnetic field sensor **160** can also include a power-on sensing module **180** configured to generate a power-on signal **180***a*. In some embodiments, the power-on signal **180***a* can be a two state signal with a first state representative of a time from a power on of the magnetic field sensor **160** to a predetermined time after the power on, and with a second state representative of a time after the predetermined time.

In view of the above, it will be understood that the bidirectional signal **176***a* can include a received command portion, an output portion representative of the self-test signal **178***a*, and another output portion representative of the signal **174***a* generated by the processing module. In some embodiments, all three components of the bidirectional signal **176***a* can exist at the same time.

It will also be understood that the output portion of the bidirectional signal **176***a* representative of the self-test signal **178***a* can be provided in response to one or more signals. In some embodiments, the output portion of the bidirectional signal **176***a* representative of the self-test signal **178***a* is generated a result of a received command portion of the bidirectional signal **176***a*. In some other embodiments, the output portion of the bidirectional signal **176***a* representative of the self-test signal **178***a* is generated a result of the power-on signal **180***a*. In some other embodiments, the output portion of the bidirectional signal **176***a* representative of the self-test signal **178***a* is generated in response to the control signal **171***a*. In some other embodiments, the output portion of the bidirectional signal **176***a* representative of the self-test signal **178***a* is generated from time to time, for example, on every rising edge of the rotation signal **174***a*, or on every Mth rising edge of the rotation signal **174***a*.

It will still further be understood that, when the output portion of the bidirectional signal **176***a* is not representative of the self-test signal **178***a*, then the output portion of the bidirectional signal **176***a* can be representative of only the rotation signal **174***a* generated by the processing module.

Referring now to FIG. **3**B, another exemplary magnetic field sensor **200** is responsive to a gear **212** having gear teeth, e.g., gear teeth **212***a*, **212***b*, **212***c*. The magnetic field sensor **200** includes two magnetic field sensing elements **202**, **204** coupled to an electronic circuit **208**. In some embodiments, the two magnetic field sensing elements **202**, **204** are separated in a direction perpendicular to an axis **214** and parallel to a gear by a distance between about 1.5 millimeters and about 3.0 millimeters. In other embodiments, the magnetic field sensing elements **202**, **204** can be separated by a distance between about 0.5 millimeters and 1.5 millimeters. In other embodiments, the magnetic field sensing elements can be separated by more than 3.0 millimeters.

The two magnetic field sensing elements **202**, **204** and the electronic circuit **208** can be disposed upon (i.e., integrated within or upon) a substrate **206**. Here, the magnetic field sensing elements **202**, **204** are shown to be Hall elements with an exaggerated size for clarity. The magnetic field sensor **200** can also include a magnet **210**. The magnet **210** is configured to generate a magnetic field, which is generally directed along the axis **214** at the position of the magnetic field sensing elements **202**, **204**. The electronic circuit **200** is configured to generate an output signal (not shown). Let it suffice here to say that the electronic circuit **200** generates a difference of two differential proximity signals **202***a*, **202***b*, and **204***a*, **204***b*. For reasons described more fully below, the magnetic field sensor **200**, using the differencing arrangement, forms an edge detector, able to detect passing edges of gear teeth, but unable to differentiate a gear tooth from a gear valley.

The output signal, when the gear **212** is rotating, is indicative speed of rotation of the gear **212** and also indicative of positions of edges of the gear teeth. However, because of the differencing arrangement, for reasons described more fully below, the magnetic field sensor **200** is unable to provide a TPOS function (which must differentiate a gear tooth from a gear valley) When the gear **212** is stationary, the magnetic field sensor **200** is unable to identify whether the magnetic field sensing elements **202**, **204** are proximate to a gear tooth or a valley in the gear **212**.

The magnet **210** can be comprised of one uniform material, and can have no central core, which is shown and described in conjunction with FIG. **3**. However, in other embodiments, the magnet **210** can have a central core the same as or similar to that shown and described in FIG. **3**.

As described above in conjunction with FIG. **3**, the central core **150** results in a low baseline when the magnetic field sensing element **142** of FIG. **3** is proximate to a valley in the gear **152**. However, the magnetic field sensor **200** uses two magnetic field sensing elements, generating a respective two differential output signals **202***a*, **202***b* and **204***a*, **204***b*. As described below in conjunction with FIG. **3**C, signals representative of the two differential output signals **202***a*, **202***b* and **204***a*, **204***b* are subtracted in the electronic circuit **208**. Thus, when the two magnetic field sensing elements **202**, **204** are proximate to a valley in the gear **212**, the low baseline is achieved due to the differencing arrangement, since the two magnetic field sensing elements **202**, **204** experience the same magnetic field. Also, when the two magnetic field sensing elements **202**, **204** are proximate to a gear tooth, e.g., **212***a*, **212***b*, **212***c*, the low baseline is also achieved, since the two magnetic field sensing elements **202**, **204** again experience the same magnetic field. Only when the two magnetic field sensing elements **202**, **204** experience different magnetic fields does a difference between the two differential signals **202***a*, **202***b* and **204***a*, **204***b* result in a higher value. The higher value may occur when one of the magnetic field sensing elements is proximate to a valley in the gear **212** and the other magnetic field sensing element is proximate to a gear tooth, i.e., an edge of one of the gear teeth is between the two magnetic field sensing elements **202**, **204**. For this reason, the magnetic field sensor **200**, having two magnetic field sensing elements used in a differential arrangement, is sometimes referred to as an “edge detector.” The edge detecting behavior makes the magnetic field sensor **200** particularly useful when it is necessary to accurately know the rotational position of the gear, which can be determined by knowledge of positions of the edges of the gear teeth represented by state transitions in the output signal from the magnetic field sensor **200**.

The differencing of the two differential signals **202***a*, **202***b* and **204***a*, **204***b* results in an improved accuracy of the magnetic field sensor **200**. For example, the magnetic field sensor **200** is not greatly influenced by external magnetic fields, i.e., noise magnetic fields, that both of the two magnetic field sensing elements **202**, **204** experience.

Referring now to FIG. **3**C, an exemplary electronic circuit **220** can include amplifiers **226**, **228** coupled to receive differential signals **222***a*, **222***b*, and **224***a*, **224***b*, respectively. The differential signal **222***a*, **222***b* can be the same as or similar to the differential signal **202***a*, **202***b* and the differential signal **224***a*, **224***b* can be the same as or similar to the differential signal **204***a*, **204***b* generated, respectively, by the magnetic field sensing elements **202**, **204** of FIG. **3**B. The amplifiers **226**, **228** are configured to generate amplified signals **226***a*, **228***a*, respectively.

The amplified signals **226***a*, **228***a* are received by a differencing module **230**, which is configured to generate a difference signal **230***a*. Characteristics and behaviors of the difference signal **230***a* will be understood from the discussion above.

The electronic circuit **220** includes only the precision rotation detector channel described above in conjunction with FIG. **3**A. An AGC **232** can be the same as or similar to the AGC **168** of FIG. **3**A, a precision rotation detector **234** can be the same as or similar to the precision rotation detector **170** of FIG. **3**A, and a calibration/running mode control module **235** can be the same as or similar to the calibration/running mode control module **171** of FIG. **3**A. The precision rotation detector **234** can generate a precision rotation detector output signal **234***a*.

The magnetic field sensor **220** can also include an output format module **236**, a self-test module **238**, and a power-on sensing module **240**, which can be the same as or similar to the output format module **176**, the self-test module **178**, and the power-on module **180** of FIG. **3**A.

Referring now to FIG. **3**D, another exemplary conventional magnetic field sensor **260** is responsive to a gear **274** having gear teeth, e.g., gear teeth **274***a*, **274***b*, **274***c*. The magnetic field sensor **260** includes three magnetic field sensing elements **262**, **264**, **266** coupled to an electronic circuit **270**. In some embodiments, the magnetic field sensing elements **262**, **264** are separated in a direction perpendicular to an axis **276** by a distance between about 1.5 millimeters and about 3.0 millimeters, and the magnetic field sensing element **266** is located midway between the magnetic field sensing elements **262**, **264**. In other embodiments, the magnetic field sensing elements **262***m* **264** can be separated by a distance between about 0.5 millimeters and 1.5 millimeters. In other embodiments, the magnetic field sensing elements **262**, **264** can be separated by more than 3.0 millimeters.

The three magnetic field sensing elements **262**, **264**, **266** and the electronic circuit **270** can be disposed upon (i.e., integrated within or upon) a substrate **268**. Here, the magnetic field sensing elements **262**, **264**, **266** are shown to be Hall elements with an exaggerated size for clarity. The magnetic field sensor **260** can also include a magnet **272**. The magnet **272** is configured to generate a magnetic field, which is generally directed along an axis **276** at the position of the magnetic field sensing elements **262**, **264**, **266**.

The electronic circuit **270** is configured to generate an output signal (not shown). An exemplary electronic circuit **270** is described below in conjunction with FIG. **3**E. Let it suffice here to say that the electronic circuit **270**, like the electronic circuit **220** of FIG. **3**C above, generates a difference of signals. Thus, for reasons described above, the magnetic field sensor **260** is an edge detector and not a tooth detector.

The output signal, when the gear **274** is rotating, is indicative speed of rotation of the gear **274**, indicative of positions of edges of the gear teeth, and can also be indicative of a direction or rotation of the gear **274**. However, for reasons described more fully above, the magnetic field sensor **260** is unable to provide a TPOS function, and, when the gear **274** is stationary, is unable to identify whether the magnetic field sensing elements **262**, **264**, **266** are proximate to a gear tooth or a valley in the gear **274**.

The magnet **272** can be comprised of one uniform material, and can have no central core, which is shown and described in conjunction with FIG. **3**. However, in other embodiments, the magnet **272** can have a central core the same as or similar to that shown and described in conjunction with FIG. **3**.

The differencing of pairs of three differential signals **262***a*, **262***b*, and **264***a*, **264***b*, and **266***a*, **266***b* results in an improved accuracy of the magnetic field sensor **260**. For example, like the magnetic field sensor **200** of FIG. **3**B, the magnetic field sensor **260** is not greatly influenced by external magnetic fields, i.e., noise magnetic fields, that the three magnetic field sensing elements **262**, **264**, **266** experience.

Referring now to FIG. **3**E, an exemplary electronic circuit **280** can be the same as or similar to the electronic circuit **220** of FIG. **3**D. The electronic circuit **280** can include amplifiers **288**, **290**, **292** coupled to receive differential signals **282***a*, **282***b*, and **284***a*, **284***b*, and **286***a*, **286***b*, respectively. The differential signal **282***a*, **282***b* can be the same as or similar to the differential signal **262***a*, **262***b*, the differential signal **284***a*, **284***b* can be the same as or similar to the differential signals **264***a*, **264***b*, and the differential signal **286***a*, **286***b* can be the same as or similar to the differential signal **266***a*, **266***b* generated, respectively, by the magnetic field sensing elements **262**, **264**, **266** of FIG. **3**D. The amplifiers **288**, **290**, **292** are configured to generate amplified signals **288***a*, **290***a*, **292***a*, respectively.

The amplified signals **288***a*, **292***a* are received by a first differencing module **294**, which is configured to generate a first difference signal **294***a*. The amplified signals **290***a*, **292***a* are received by a second differencing module **296**, which is configured to generate a second difference signal **296***a*. Characteristics and behaviors of the difference signals **294***a*, **296***a* will be understood from the discussion above.

The electronic circuit **280** includes only precision rotation detector channels described above in conjunction with FIG. **3**A. Only one of the two precision rotation detector channels is described herein as being representative of the other precision rotation detector channel. An AGC **290** can be the same as or similar to the AGC **168** of FIG. **3**A, a precision rotation detector **302** can be the same as or similar to the precision rotation detector **170** of FIG. **3**A, and a calibration/running mode control module **305** can be the same as or similar to the calibration/running mode control module **171** of FIG. **3**A. The precision rotation detector **302** can generate a precision rotation detector output signal **302***a*.

A speed/direction module **306** can be coupled to receive the precision rotation detector output signal **302***a* and also another precision rotation detector output signal **304***a*. The speed/direction module **306** is configured to generate an output signal **306***a* representative of a speed of rotation and a direction of rotation of the gear **274**. It will be understood that the direction information can be determined by way of a phase difference of the two precision rotation detector output signals **302***a*, **304***a*, and the speed information can be determined by way of a frequency of either one of the two precision rotation detector output signals **302***a*, **304***a*.

The electronic circuit **280** can also include an output format module **308**, a self-test module **310**, and a power-on sensing module **312**, which can be the same as or similar to the output format module **176**, the self-test module **178**, and the power-on module **180** of FIG. **3**A.

The self-test module **310** can be coupled to receive more signals than the self-test module **238** of FIG. **3**C. Namely, the self-test module **310** can be coupled to receive first and second proximity signals **294***a*, **296***aa*, respectively, first and second threshold signals **302***b*, **304***b*, respectively, and first and second gain controlled (AGC0 signals **298***a*, **300***a*, respectively. The additional signals represent a replication of self-test functions (such as those described below in conjunction with FIG. **4**) within the self-test module **310**.

While magnetic field sensors described above in conjunction with FIGS. **3**-**3**E are shown to include respective automatic gain control circuits (AGCs) configured to generate respective gain controlled signals, in other embodiments, the AGCs can be replaced by fixed gain amplifiers or buffers, in which case, the gain controlled signals are replaced by fixed gain signals. For embodiments in which the gain of the amplifiers are fixed, it should be understood that the gain of the amplifiers can be greater that one, less than one, or one. Both the gain controlled signals and the fixed gain signals are referred to herein as "magnetic-field-responsive signals," which are representative of, or the same as, the proximity signals.

Referring now to FIG. **4**, in which like elements of FIGS. **3** and **3**A are shown having like reference designations, a magnetic field sensor **340** can include the processing module and the self-test module **178** of FIG. **3**A. Here, the self-test module **178** is shown in greater detail.

The magnetic field sensor **340** can include a Hall Effect element **344** configured to generate a differential signal **344***a*, **344***b*, which is received by the processing module. The Hall Effect element **344** can be coupled to receive drive signals **342***a* from an element drive circuits **342**.

The magnetic field sensor **340** can include a plurality of nodes or lead frame pins. A first node **340***a* is coupled to receive a power supply voltage, Vcc. A second node **340***b* is coupled to ground. A third node **340***c* provides the bidirectional signal **176***a*, which, at some times includes an output portion representative of rotation of the gear **152** of FIG. **3**, at some other times includes an output portion representative of a self-test of the magnetic field sensor **340**, and at some other times includes an input portion comprising a command signal from outside of the magnetic field sensor **340**.

It should be recognized that detailed aspects of the self-test module **178** can be implemented with microcode instructions and a micro machine, or the detailed aspects can be implemented in gates, as may be generated, for example, by a hardware description language (HDL).

As described above in conjunction with FIG. **3**A, the self-test module **178** can be coupled to receive one or more of the amplified proximity signal **164***a*, the gain controlled (AGC) signal **168***a*, the threshold signal **170***b*, the control signal **171***a*, or the power on signal **180***a*.

In one self-test aspect described more fully below, the self-test module **178** can include an analog-to-digital converter (ADC) coupled to receive the amplified signal **164***a*, which is an analog signal, and convert the amplified signal **164***a* to a digital signal **346***a*. The self-test module **178** can include a signal peak detector **350** coupled to receive the converted signal **346***a* and configured to generate an output signal **178***ab* representative of peak values of the converted signal **346***a*.

In another self-test aspect described more fully below, the self-test module **178** can include a sample and hold circuit **347** coupled to receive the proximity signal **164***a* and configured to generate a plurality of analog samples within a signal **347***a*. A gate circuit **351**, or switch circuit, can be coupled to receive the signal **347***a*. The gate circuit **351** is configured to generate an output signal **178***ac* from the gate circuit **351** representative of analog samples within the signal **347***a*.

In other self-test aspect described more fully below, the self-test module **178** can include another gate circuit **353**, or switch circuit, coupled to receive the converted signals **346***a*. The gate circuit **353** is configured to generate an output signal **178***ad* representative of all of or selected ones of digital samples within the signal **346***a*.

In another self-test aspect, described more fully below, the self-test module **178** can include a proper peak/proper DC offset detector **352** coupled to receive the converted signal **346***a* (also referred to herein as a proximity signal). The proper peak/proper DC offset detector **352** can be configured to categorize one or more characteristics of the proximity signal **346***a* into a plurality of potential categories. The plurality of potential categories is representative of a plurality of discrete self-test states of the proximity signal **346***a*. The proper peak/proper DC offset detector **352** is configured to generate a signal **178***ae* representative of at least one of the plurality of potential categories into which at least one of the one or more characteristic values was categorized.

In another self-test aspect described more fully below, the self-test module **178** can include an analog-to-digital converter **348** coupled to receive the threshold signal **170***b* and configured to generate a converted signal **348***a*. The self-test module **178** can also include an analog-to-digital converter **349** coupled to receive the gain controlled signal **168***a* and configured to generate a converted signal **349***a*. The self-test module **178** can include a proper threshold detector **354** coupled to receive the converted signal **348***a* and coupled to receive the converted signal **349***a*. The proper threshold detector **354** is configured to identify a plurality of peak values of the gain controlled signal **168***a*, configured to identifying a plurality of threshold values of the threshold signal **170***b*, configured to generate one or more difference values by differencing the identified peak values and associated identified threshold values, and configured to categorize the one or more difference values into a plurality of potential categories. The plurality of potential categories is representative of a plurality of self-test states of the proximity signal. The proper threshold detector **354** is configured to generate a signal **178***aa* representative of at least one of the plurality of potential categories into which at least one of the one or more characteristic values was categorized.

In another self-test aspect described more fully below, the self-test module **178** can include a variation detector **353** coupled to receive the converted signal **346***a*. The variation detector is configured to identify one or more variation values of the converted signal **346***a*, i.e., of the proximity signal **164***a*. The variation values can include, but are not limited to, values representative of a variation of peak-to-peak values, values representative of a variation of (positive and/or negative) peak values, values representative of a variation of mean values (i.e., DC offset values), or values representative of a variation of root-mean-square (rms) values. In some embodiments, the variation values are standard deviation values. The variation detector **353** is configured to generate a signal **178***af* representative of the one or more variation values.

In view of the above, the self-test module **178** is configured to generate any one or more of self-test signals **178***aa*, **178***ab*, **178***ac*, **178***ad*, **178***ae*, **178***af*.

In some embodiments, the self-test module **178** includes a sequence module **344** configured to generate a sequence signal **344***a*. The sequence signal **344***a* can cause any one or more of self-test signals **178***aa*, **178***ab*, **178***ac*, **178***ad*, **178***ae* to be generated in any sequence. However, in other embodiments, the self-test module **178** generates only one of the self-test signals **178***aa*, **178***ab*, **178***ac*, **178***ad*, **178***ae*, **178***af*, and portions of the self-test module **178** that are not used are omitted.

Any one or more of the self-test signals **178***aa*, **178***ab*, **178***ac*, **178***ad*, **178***ae*, **178***af* can be communicated to the output format module **176**, and any one or more of the self-test signals **178***aa*, **178***ab*, **178***ac*, **178***ad*, **178***ae*, **178***af* can be communicated within a self-test signal portion of the bidirectional signal **176***a*. As described above, the self-test signal portion of the bidirectional signal **176***a* can be generated under control of one or more of the plurality of control signals, for example, under control of the power on the control signal **180***a*, under control of the control signal **171***a*, or under control of the command portion of the bidirectional signal **176***a*. The command portion of the bidirectional signal **176***a* can be communicated to the self-test module **178** via a command signal **176***b*.

In some alternate embodiments, any one or more of the self-test signals **178***aa*, **178***ab*, **178***ac*, **178***ad*, **178***ae*, **178***af* can be communicated to another node **340***d*, or lead frame pin. Communication of any one or more of the self-test signals **178***aa*, **178***ab*, **178***ac*, **178***ad*, **178***ae*, **178***af* to the node **340***d* can occur either in combination with the communication of any one or more of the self-test signals **178***aa*, **178***ab*, **178***ac*, **178***ad*, **178***ae*, **178***af* within the self-test portion of the bidirectional signal **176***a* or instead of the communication within the self-test portion of the bidirectional signal **176***a*.

Referring briefly to FIG. **3**E, it will be understood that the various modules of the self-test module **178** can be replicated with the self-test module **310** of FIG. **3**E to accommodate a second precision rotation detector.

While the magnetic field sensor **341** described above in conjunction with FIG. **4** is shown to include an automatic gain control circuit (AGC) **168** configured to generate a respective gain controlled signal **168***a*, in other embodiments, the AGC **168** can be replaced by a fixed gain amplifier or buffer. Thus, gain controlled signals described in figures below can be replaced by fixed gain signals.

Referring now to FIG. **5**, a graph **380** has a vertical axis with a scale in units of volts and a horizontal axis with a scale in units of time in arbitrary units. A signal **382** is representative of the amplified signal **164***a* (i.e., proximity signal) of FIGS. **3**A and **4**. However, the signal **382** can also be representative of the amplified signals **230***a*, **294***a*, **296***a* of FIGS. **3**C and **3**E.

As described above, the signal **382** has positive and negative peaks corresponding to gear teeth and valleys in a gear when the gear is rotating. As shown, the amplified signal **382** can have fluctuations in DC offset, fluctuations in peak amplitude, and fluctuations in peak-to-peak amplitudes as the gear rotates. The fluctuations can result from the above described wobble and/or from the above described radial asymmetry of the gear as it rotates.

A signal **384**, here shown in analog form, is representative of digitized values of the amplified signal **382** as generated by an analog-to-digital converter, for example, the analog-to-digital converter **346** of FIG. **4**.

As described above, in some embodiments, digital values (i.e., the converted signal **346***a* of FIG. **4**) of which the signal **384** is representative, are communicated by the self-test module **178**, for example, to the engine control processor in an automobile for analysis of the magnitudes of the fluctuations of the signal **384**. If the fluctuations are large enough, the engine control processor can give an indication of a failure.

Referring now to FIG. **5**A, a first list of numbers **390** is representative of analog values of the signal **382** of FIG. **5** (i.e., samples of the analog proximity signal **164***a* of FIG. **4**) at different respective times. In some embodiments, the magnetic field sensors described above can provide the sampled analog values **390** as self-test signal **178***ac* of FIG. **4**.

A second list of numbers **400** is representative of digital values corresponding to the values of the signal **384** of FIG. **5** (i.e., the converted signal **346***a* of FIG. **4**) at different respective times. In some embodiments, the magnetic field sensors described above can provide the digital values **400** as the self-test signal **178***ad* of FIG. **4**.

A third list of numbers **410** is representative of positive and negative peaks of the signal **384** of FIG. **5** at different respective times. In some embodiments, the magnetic field sensors described above can provide the positive and negative peak values **410** as the self-test signal **178***ab* of FIG. **4**.

It should be recognized that the values **390**, **400**, **410** do not directly identify passing, failing, or marginal conditions of the magnetic field sensors that generate the values. Another processor, for example, the above-described engine control processor, receives the values and makes the determination.

It should be appreciated that flowcharts shown below correspond to the below contemplated technique which would be implemented in a magnetic field sensor, e.g., the magnetic field sensor **340** of FIG. **4**. Rectangular elements (typified by element **422** in FIG. **6**), herein denoted "processing blocks," represent computer software instructions or groups of instructions or gate level hardware equivalents. Diamond shaped elements, herein denoted "decision blocks," represent computer software instructions, or groups of instructions, or gate level hardware equivalents, which affect the execution of the computer software instructions represented by the processing blocks.

In some embodiments, the processing and decision blocks represent steps performed by functionally equivalent circuits such as a digital signal processor circuit or an application specific integrated circuit (ASIC). The flow diagrams do not depict the syntax of any particular programming language. Rather, the flow diagrams illustrate the functional information one of ordinary skill in the art requires to fabricate circuits or to generate computer software to perform the processing required of the particular apparatus. It should be noted that many routine program elements, such as initialization of loops and variables and the use of temporary variables are not shown. It will be appreciated by those of ordinary skill in the art that unless otherwise indicated herein, the particular sequence of blocks described is illustrative only and can be varied without departing from the spirit of the invention. Thus, unless otherwise stated the blocks described below are unordered meaning that, when possible, the steps can be performed in any convenient or desirable order.

Referring now to FIG. **6**, a method **420** is associated with the self-test signals **178***ab*, **178***ac*, **178***ad* of FIG. **4** and associated with the values **390**, **400**, **410** of FIG. **5**A.

The method **420** begins at block **422**, where the proximity signal, for example, the proximity signal **164***a* of FIG. **4**, is received, for example, by the self-test module **178** of FIG. **4**. At block **424**, the method **420** waits for either a command portion of the bidirectional signal **176***a* of FIG. **4**, or alternatively, waits for a particular state of a particular state of one of the alternate control signals, for example, the power on signal **180***a* of FIG. **4** or the control signal **171***a* of FIG. **4**.

At block **426**, upon receiving the command or alternate signal at block **422**, the method converts, or alternatively samples, the proximity signal **164***a* of FIG. **4**.

At block **428**, the process identified desired portions of the converted or sampled signal. In some embodiments, the desired portions are all of the converted or sampled signal. In some embodiments, the desired portions are fewer than all of the converted or sampled signal.

At block **430**, desired portions of the converted or sampled signal are communicated, for example, within one or more of the self-test signals **178***aa*, **178***ab*, **178***ac* of FIG. **4**.

It will be appreciated from discussion above that the desired portions of the converted or sampled signal can include digital samples of the proximity signal **164***a* or analog samples of the proximity signal **164***a*. The desired portions of the converted or sampled signal can include only some of the samples, for example, only peak values, or the desired portions of the converted or sampled signal can include substantially all of the samples of the proximity signal.

Referring now to FIG. **7**, in some embodiments, the proper peak/proper DC offset detector **352** described above uses two predetermined self-test thresholds **450**, **452** to identify amplified signals (e.g., the amplified or proximity signal **164***a* of FIGS. **1**A and **4**) that have sufficient amplitude. An amplified signal **456**, which does not cross the self-test thresholds **450**, **452**, has too low of an amplitude and can be identified by the above-described proper peak/proper DC offset detector **352** to be indicative of a failing condition. An amplified signal **454**, which does cross the self-test thresholds **450**, **452**, has an acceptable amplitude and can be identified by the above-described proper peak/proper DC offset detector **352** to be indicative of a passing condition. The passing or failing conditions can be communicated in the self-test signal **178***ae* of FIG. **4**.

Referring now to FIG. **8**, an amplified signal **470** is representative of amplified signals above (e.g., the amplified or proximity signal **164***a* of FIGS. **1**A and **4**). The amplified signal has the fluctuations described above in conjunction with FIG. **5**. Peak-to-peak amplitudes are shown by arrows, e.g., arrow **472**, on each half cycle of the amplified signal **470**.

Referring now to FIG. **8**A, the peak-to-peak amplitudes of cycles of the amplified signal **470** of FIG. **8** are compared with a predetermined self-test threshold **480**. Peak-to-peak amplitudes above the self-test threshold **480** are categorized as being indicative of a passing condition and peak-to-peak amplitudes below the self-test threshold **480** are categorized as being indicative of a failing condition.

The term "characteristic value" is used in conjunction with FIG. **8**A to indicate peak-to-peak values.

Exemplary category values **486** are indicative of the passing and failing conditions of the characteristic values, i.e., the peak-to-peak values, of the amplified signal **470** of FIG. **5**. Within the exemplary category values **486**, a category value of zero is indicative of a failing condition and a category value of one is indicative of a passing condition. However, in other embodiments, lower category values can be indicative of the passing condition.

In some embodiments, the category values **486** are identified by and communicated by the above-described proper peak/proper DC offset detector **352** of FIG. **4**. The category values **486** can be communicated in the self-test signal **178***ae* of FIG. **4**. In some embodiments, all of the category values are communicated. In other embodiments, only a category value indicative a worst case category is communicated, here a zero indicative of a failing condition.

It will be understood that, since only one predetermined threshold **480** is used, the process represented by FIG. **8**A can directly identify only passing and failing conditions and is unable to identify marginal condition. However, in some embodiments, the category values **486** can be further processed, for example, by the proper peak/proper DC offset detector **352** of FIG. **4** in order to identify marginal conditions. A marginal condition can be identified and communicated, for example, by detecting a rate at which the failures, i.e., category values equal to zero, occur. In other words, category values of zero that occur within a certain range of rates can be indicative of a marginal failure. Thus, in some embodiments, passing conditions, failing conditions, and marginal conditions can be communicated within the self-test signal **178***ae* of FIG. **4**, even when using only one predetermined threshold **480**.

Still further, in other embodiments, the category values **486** can be combined, for example, to generate one or more failures (i.e., zero category values) per time value(s), or to generate a total of category values per time. In some embodiments, the combined category values, e.g., the zero category value per time or the total category values per time, are communicated within the self-test signal **178***ae* of FIG. **4**.

Referring now to FIG. **9**, the peak-to-peak amplitudes of cycles of the amplified signal **470** of FIG. **8** are compared with a plurality of predetermined self-test thresholds **490**, **492**, **494**, **496**. Peak-to-peak amplitudes above the self-test threshold **494** are categorized being indicative of a passing condition. Peak-to-peak amplitudes below the self-test threshold **490** are categorized as being indicative of a failing condition. Peak-to-peak amplitudes between self-test thresholds **490** and **492** are categorized as being indicative of a marginal and unacceptable condition. Peak-to-peak amplitudes between self-test test thresholds **492** and **494** are categorized as being indicative of a marginal but acceptable condition.

The term "characteristic value" is used in conjunction with FIG. **9** to indicate peak-to-peak values.

Category values **498** are indicative of the above-described four possible conditions of the characteristic values, i.e., the peak-to-peak values, of the amplified signal **470** of FIG. **5**. Here, a category value of three is indicative of the passing condition, a category value of two is indicative of the marginal but acceptable condition, a category value of one is indicative of the marginal and unacceptable condition, and the category value of zero is indicative of the failing condition.

In some embodiments, the category values **498** are identified by and communicated by the proper peak/proper DC offset detector **352** of FIG. **4** within the self-test signal **178***ae* of FIG. **4**. In some embodiments, all of the category values **498** are communicated. In other embodiments, only a category value indicative a predetermined category is communicated, for example, a zero, a one, or a two.

In other embodiments, the category values are combined, for example, to generate one or more failures (i.e., zero category values) per time value(s), or to generate a total of category values per time. Other combinations per time are also possible. In some embodiments, the combined category values, e.g., the zero category value per time or the total category values per time, are communicated by the above-described proper peak/offset detector **352** of FIG. **4**, and upon command, the combined category values are communicated within the self-test signal **178***ae* of FIG. **4**.

Referring now to FIG. **10**, a method **500** pertains to the subject matter of FIGS. **7**, **8**, **8**A, and **9**.

The method **500** begins at block **502**, where the proximity signal, for example, the proximity signal **164***a* of FIG. **4**, is received, for example, by the self-test module **178** of FIG. **4**. At block **504**, the method **500** waits for either a command portion of the bidirectional signal **176***a* of FIG. **4**, or alternatively, waits for a particular state of one of the alternate control signals, for example, the power on signal **180***a* of FIG. **4** or the control signal **171***a* of FIG. **4**.

At block **506**, upon receiving the command or alternate signal at block **502**, the method converts (e.g., converts to digital values) the proximity signal **164***a* of FIG. **4**.

At block **508**, the method, i.e., the proper peak/proper DC offset detector **352** of FIG. **4**, identifies the peak-to-peak values in the converted proximity signal. Peak-to-peak values are represented for example, by an arrow **499** of FIG. **9**.

At block **510**, the method categorizes peak-to-peak values into a plurality of categories, for example, pass, fail, and marginal categories.

At block **512**, the method communicates categories into which the peak-to-peak values fall, for example, within the self-test signal **178***ae* of FIG. **4**.

Referring now to FIG. **10**A, a method **520** pertains to the subject matter of FIGS. **8**, **8**A, and **9**.

The method **520** begins at block **522**, where the proximity signal, for example, the proximity signal **164***a* of FIG. **4**, is received, for example, by the self-test module **178** of FIG. **4**. At block **524**, the method **520** waits for either a command portion of the bidirectional signal **176***a* of FIG. **4**, or alternatively, waits for a particular state of one of the alternate control signals, for example, the power on signal **180***a* of FIG. **4** or the control signal **171***a* of FIG. **4**.

At block **526**, upon receiving the command or alternate signal at block **422**, the method converts (e.g., converts to digital values) the proximity signal **164***a* of FIG. **4**.

At block **528**, the method, i.e., the proper peak/proper DC offset detector **352** of FIG. **4**, identifies the peak-to-peak values in the converted proximity signal. Peak-to-peak values are represented for example, by an arrow **499** of FIG. **9**.

At block **530**, the method categorizes peak-to-peak values into a plurality of categories, for example, pass, fail, and marginal categories.

Blocks **538** show additional details related to block **512** of FIG. **10**.

At block **532**, the method generates category values associated with the categories. The category values **498** of FIG. **9** are representative of the category values.

At block **534**, the method identifies category values above a predetermined category value threshold. Referring briefly to FIG. **9**, the predetermined category value threshold can be zero, one, or two.

At block **536**, the method communicates at least one of the plurality of potential categories into which at least one of the one or more characteristic values was categorized that is associated with a category value greater than the predetermined threshold category value. Referring again briefly to FIG. **9**, for example, if the predetermined category value threshold is two, categories having measured peak-to peak values with category values of one and zero are communicated.

Referring now to FIG. **11**, four signals **550**, **554**, **558**, **562** are representative of the proximity signal **164***a* of FIG. **4** taken at different times, for example, at different angular rotations of a gear sensed by the magnetic field sensor **340** of FIG. **4**, or at different times of the day, or at different operating temperatures.

The four signals **550**, **554**, **558**, **562** have four different characteristic values, here four different mean values (i.e., DC offsets) **552**, **556**, **560**, **564**, respectively.

Referring now to FIG. **11**A, in which like elements of FIG. **11** are shown having like reference designations, a range **570** between upper and lower mean value thresholds **566**, **568** represents an acceptable range of mean values, within which the mean values **556**, **560** fall. Thus, the signals **554**, **558** represent signals categorized as passing signals and the signals **550**, **562** represent signals categorized as failing signals, i.e., their DC offsets are too large.

Category values are shown for each of the four signals **550**, **554**, **558**, **562**.

While only pass and fail categories are represented by the range **570**, in other embodiments, there can be additional ranges that are indicative of marginal conditions.

Referring now to FIG. **11**B, in which like elements of FIGS. **11** and **11**A are shown having like reference designations, the four signals **550**, **554**, **558**, **562** are repositioned (becoming signals **550***a*, **554***a*, **558***a*, **562***a*) for clarity to show that they have another eight different characteristic values, here four different positive peak values and four different negative peak values, which are also representative of four different peak-to-peak values where the signals **550***a*, **554***a*, **558***a*, **562***a* are symmetrical.

A range **570** between positive peak thresholds **572**, **574** and a range **582** between negative peak thresholds **578**, **580** represent acceptable ranges of peak amplitudes of the signals **550***a*, **554***a*, **558***a*, **562***a*. Thus, the signals **554***a*, **562***a* represent signals categorized as passing signals and the signals **550***a*, **558***a* represent signals categorized as failing signals, i.e., their amplitudes are too small.

While only pass and fail categories are represented by the ranges **576**, **582**, in other embodiments, there can be additional ranges that are indicative of marginal conditions.

Category values are shown for each of the four signals **550***a*, **554***a*, **558***a*, **562***a*.

In some embodiments, only one of the failing conditions of FIGS. **11**A, **11**B is communicated in the self-test signal **178***ae* of FIG. **4**. In other embodiments, both of the failing conditions of FIGS. **11**A, **11**B are communicated in the self-test signal **178***ae* of FIG. **4**. Singular arrangements are described below in conjunction with FIGS. **12** and **12**A. In still other embodiments, the failing conditions of FIGS. **11**A, **11**B are further combined and the combination is communicated. Combined arrangements are described more fully below in conjunction with FIG. **12**C.

Referring now to FIG. **12**, a process **600** is representative of use of DC offsets alone as in FIG. **11**A.

The method **600** begins at block **602**, where the proximity signal, for example, the proximity signal **164***a* of FIG. **4**, is received, for example, by the self-test module **178** of FIG. **4**. At block **604**, the method **600** waits for either a command portion of the bidirectional signal **176***a* of FIG. **4**, or alternatively, waits for a particular state of one of the alternate control signals, for example, the power on signal **180***a* of FIG. **4** or the control signal **171***a* of FIG. **4**.

At block **606**, upon receiving the command or alternate signal at block **604**, the method converts (e.g., converts to digital values) the proximity signal **164***a* of FIG. **4**.

At block **608**, the method, i.e., the proper peak/proper DC offset detector **352** of FIG. **4**, identifies one or more DC offset values in the converted proximity signal.

At block **610**, the method categorizes DC offset values into a plurality of categories, for example, pass, fail, and marginal categories.

At block **612**, the method communicates categories, e.g., self-test categories (e.g., category values), into which the DC offset values fall, for example, within the self-test signal **178***ae* of FIG. **4**.

Referring now to FIG. **12**A, a process **620** is representative of use of positive and negative peak values as in FIG. **11**B.

The method **620** begins at block **622**, where the proximity signal, for example, the proximity signal **164***a* of FIG. **4**, is received, for example, by the self-test module **178** of FIG. **4**. At block **624**, the method **620** waits for either a command portion of the bidirectional signal **176***a* of FIG. **4**, or alternatively, waits for a particular state of one of the alternate control signals, for example, the power on signal **180***a* of FIG. **4** or the control signal **171***a* of FIG. **4**.

At block **626**, upon receiving the command or alternate signal at block **624**, the method converts (e.g., converts to digital values) the proximity signal **164***a* of FIG. **4**.

At block **628**, the method, i.e., the proper peak/proper DC offset detector **352** of FIG. **4**, identifies one or more peak values in the converted proximity signal.

At block **630**, the method categorizes the peak values into a plurality of categories, for example, pass, fail, and marginal categories.

At block **632**, the method communicates categories e.g., self-test categories (e.g., category values), into which the peak values fall, for example, within the self-test signal **178***ae* of FIG. **4**.

Referring now to FIG. **12**B, a method **640** uses deviation values, and, in particular, standard deviation values.

The method **640** begins at block **642**, where the proximity signal, for example, the proximity signal **164***a* of FIG. **4**, is received, for example, by the self-test module **178** of FIG. **4**. At block **644**, the method **640** waits for either a command portion of the bidirectional signal **176***a* of FIG. **4**, or alternatively, waits for a particular state of one of the alternate control signals, for example, the power on signal **180***a* of FIG. **4** or the control signal **171***a* of FIG. **4**.

At block **646**, upon receiving the command or alternate signal at block **644**, the method converts (e.g., converts to digital values) the proximity signal **164***a* of FIG. **4**.

At block **648**, the method, i.e., the proper variation detector **353** of FIG. **4**, identifies one or more variation values associated with the converted proximity signal. As described above, the variation values can be associated with a variety of characteristics of the proximity signal, including, but not limited to variation of peak-to-peak values, variation of peak values, variation of root mean square (RMS) values, and variation of DC offset values. In some embodiments, the variation values are standard deviation values.

At block **650**, the method categorizes the variation values into a plurality of categories, for example, pass, fail, and marginal categories.

At block **652**, the method communicates categories e.g., self-test categories (e.g., category values), into which the deviation values fall, for example, within the self-test signal **178***af* of FIG. **4**.

Referring now to FIG. **12**C, a process **660** is representative of use of DC offset values as in FIG. **11**A, in combination with positive and negative peak values as in FIG. **11**B.

The method **660** begins at block **662**, where the proximity signal, for example, the proximity signal **164***a* of FIG. **4**, is received, for example, by the self-test module **178** of FIG. **4**. At block **664**, the method **660** waits for either a command portion of the bidirectional signal **176***a* of FIG. **4**, or alternatively, waits for a particular state of one of the alternate control signals, for example, the power on signal **180***a* of FIG. **4** or the control signal **171***a* of FIG. **4**.

At block **666**, upon receiving the command or alternate signal at block **664**, the method converts (e.g., converts to digital values) the proximity signal **164***a* of FIG. **4**.

At block **668**, the method, i.e., the proper peak/proper DC offset detector **352** of FIG. **4**, identifies one or more first characteristic values in the converted proximity signal. In some embodiments, the first characteristic values are DC offset values in accordance with FIG. **11**A.

At block **670**, the method, i.e., the proper peak/proper DC offset detector **352** of FIG. **4**, identifies one or more second characteristic values in the converted proximity signal. In some embodiments, the second characteristic values are peak values in accordance with FIG. **11**B.

At block **672**, the method categorizes the first and second characteristic values into first and second plurality of categories, for example, pass fail, and marginal categories. The second plurality of categories may or may not be the same categories as the first plurality of categories.

At block **674**, the method assigns category values to the first and second characteristic values. Two sets of category values are shown above in conjunction with FIGS. **11**A and **11**B.

At block **676**, the category values can be weighted, for example, in proportion to importance. Using the category values of FIGS. **11**A and **11**B as examples, the category values shown in FIG. **11**A can be assigned a weighting factor of one and the category values shown in FIG. **11**B can be assigned a weighting factor of two, indicating that those category values have higher importance.

Thus, the weighted category values become those shown below in Table 1.

TABLE 1

Signal	Original Category Values	Weighting factor	Weighted Category Values
550	0	1	0
554	1	1	1
558	1	1	1
562	0	1	0
550a	0	2	0
554a	1	2	2
558a	0	2	0
562a	1	2	2

At block **678**, the weighted category values can be combined in any one of a variety of ways. In one example shown in Table 2 below, the weighted category values are summed.

TABLE 2

Signals	First Weighted Category Values	Second Weighted Category Values	Combined Weighted Category Values
550/550a	0	0	0
554/554a	1	2	3
558/558a	1	0	1
562/562a	0	2	2

It should be understood that, in a particular sense, the column of combined weighted category values of Table 2 is associated with a combined set of categories. For example, the combined weighted category value of zero is representative of failures of two different signal characteristics at the same time, namely, both the signal DC offset value of the associated signal is out of range and the peak value of the associated signal is out of range.

At block **680**, one or more categories (e.g., combined weighted category values) are communicated. As with other category values described above, in some embodiments, combined weighted category values of Table 2 are identified by and communicated by the proper peak/proper DC offset detector **352** of FIG. **4** within the self-test signal **178***ae* of FIG. **4**. In some embodiments, all of the combined weighted category values of Table 2 are communicated. In other embodiments, only a combined weighted category value indicative a predetermined combined category is communicated, for example, a zero, a one, or a two.

In other embodiments, the combined weighted category values are further combined, for example, to generate one or more failures (i.e., zero combined weighted category values) per time value(s), or to generate a total of combined weighted category values per time. Other combinations per time are also possible. In some embodiments, the combined weighted category values, e.g., the zero combined weighted category value per time or the total combined weighted category values per time, are communicated by the above-described proper peak/offset detector **352** of FIG. **4**, and upon command, the further combined weighted category values are communicated within the self-test signal **178***ae* of FIG. **4**.

Optionally, at block **682**, one or more of the first and second categories (e.g., category values) of Table 1 can be communicated in addition to or in place of the combined weighted category values of Table 2.

Referring now to FIG. **13**, an electronic circuit **700** includes a precision rotation detector **722**, a TPOS detector **716**, and an automatic gain control **714**. The precision rotation detector **722**, the TPOS detector **716**, and the automatic gain control **714** can be the same as or similar to the precision rotation detector **170**, the TPOS detector **166**, and the automatic gain control **168** of FIG. **4**. A proximity signal **702** can be the same as or similar to the proximity signal **164***a* of FIG. **4**.

The TPOS detector **718** can be comprised of a comparator **716** coupled to receive the proximity signal **702** at a first input node and coupled to receive a predetermined threshold signal (i.e., voltage) at a second input node. The TPOS detector **718** is configured to generate a TPOS output signal **718***a*, which can be the same as or similar to the TPOS output signal **166***a* of FIG. **4**.

The automatic gain control **714** is coupled to receive the proximity signal **702**. In some embodiments, the proximity signal **702** has a DC offset correction applied by an automatic offset controller **704** and an offset digital-to-analog converter (DAC) **706** via a summing node **708**. The AGC **714** is configured to generate a gain controlled signal **714***a*, which can be the same as or similar to the gain controlled signal **168***a* of FIG. **4**.

The AGC **714** can be controlled by an AGC DAC **710**. It should be understood that the proximity signal **702** is representative of the magnetic field experienced by one or more magnetic field sensors, for example, the magnetic field sensors **14***a*, **14***b* of FIG. **1**.

The gain controlled signal **714***a* is provided as an input to a comparator **752**. The comparator **752** is also coupled to receive a threshold signal **750**. Generation of the threshold signal **750** is further described below.

The threshold signal **750** switches between two signals **750***a*, **750***b*, a first one **750***a* of which is a first predetermined percentage (e.g., sixty percent) of a peak-to-peak value of the gain controlled signal **714***a* and a second one **750***b* of which is a second predetermined percentage (e.g., forty percent) of the peak-to-peak value of the gain controlled signal **714***a*. The first and second threshold voltages **750***a*, **750***b* are, therefore, centered about a fifty percent point of the gain controlled signal **714***a*. The comparator **752** generates an output signal **752***a* having edges closely associated with the times when the gain controlled signal **714***a* crosses the two thresholds **750***a*, **750***b*, which times are near to times when the gain controlled signal **714***a* is near its fifty percent point. The output signal **752***a* can be the same as or similar to the high precision rotation detector output signal **170***a* of FIG. **4**.

The threshold voltages **750***a*, **750***b* within the threshold signal **750** are generated by counters **726**, **728**, logic circuits **724**, **730**, a PDAC **736**, an NDAC **738**, comparators **732**, **734**, a resistor ladder **740**, and transmission gates **744**, **746**. The comparator **732** is coupled to receive the gain controlled signal **714***a* and an output signal **736***a* generated by the PDAC **736**, and, by way of feedback provided by the logic circuit **724** and the counter **726**, causes the output of the PDAC **736** (i.e., the PDAC voltage **736***a*) to track and hold positive peaks of the gain controlled signal **714***a*. Similarly, the comparator **734** is coupled to receive the gain controlled signal and an output signal **738***a* generated by the NDAC **738**, and, by way of feedback provided by the logic **730** and the counter **728**, causes the output of the NDAC **738** (i.e., the NDAC voltage **738***a*) to track and hold negative peaks of the gain controlled signal **714***a*. Therefore, the differential voltage between the output **736***a* of the PDAC **736** and the output **738***a* of the NDAC **738** is representative of a peak-to-peak amplitude of the gain controlled signal **714***a*.

Operation of the PDAC and NDAC is further described in U.S. Pat. No. 7,365,530, issued Apr. 29, 2008, which is assigned to the assignee of the present application, and which is incorporated by reference herein in its entirety.

The PDAC and NDAC voltages **736***a*, **738***a*, respectively, are provided to opposite ends of a resistor ladder **740**. Transmission gates **744**, **746** provide the threshold voltage **750** as one of two voltage values as described above, depending upon control voltages (not shown) applied to the transmission gates **744**, **746**. The control voltages can be related to the output signal **752***a*.

Referring now to FIG. **14**, a graph **800** has a vertical scale in units of volts in arbitrary units and a horizontal scale in units of time in arbitrary units. A gain controlled signal **802**, which can be the same as or similar to the gain controlled (AGC) signal **714***a* of FIG. **13**, is compared against threshold signal values **804***a*, **804***b*, **806***a*, **806***b*, which can be the same as or similar to threshold signal values **750***a*, **750***b* of FIG. **13**. Switchpoint times, A, B, C, D represent times of edge transitions of the output signal **752***a* of FIG. **13**.

A PDAC signal **814***a*, **814***b* can be the same as or similar to the PDAC signal **736***a* of FIG. **13** and an NDAC signal **816***a*, **816***b*, **816***c* can be the same as or similar to the NDAC signal **738***a* of FIG. **13**. Lower thresholds **804***a*, **804***b* and upper thresholds **806***a*, **806***b* are generated as described above, from percentages, e.g., forty percent and sixty percent of the difference between the PDAC signal **814** and the NDAC signal **816**.

Each pair of thresholds, for example, the thresholds **806***a*, **804***a*, are derived from PDAC and NDAC signals, e.g., **814***a*, **816***a* associated with preceding positive and negative peaks of the gain controlled signal **802**. Thus, a sudden change of the amplitude of the gain controlled signal **802**, as is shown in the last full cycle of the gain controlled signal **802**, can result in the gain controlled signal **802** being compared against improper thresholds.

Referring now to FIG. **15**, in which like elements of FIG. **14** are shown having like reference designations, a region **826** is representative of a minimum acceptable margin between positive peaks of the gain controlled signal **802** and the upper thresholds **806***a*, **806***b*. Similarly, a region **828** is representative of a minimum acceptable margin between negative peaks of the gain controlled signal **802** and the lower thresholds **804***a*, **804***b*.

The region **826** can be bounded by the upper threshold values, i.e., by a line **820**, and by the upper threshold values plus a margin, e.g., by a line **822**. The region **828** can be bounded by the lower threshold values, i.e., by a line **818**, and by the lower threshold values minus a margin, e.g., by a line **824**. The margins of the upper and lower regions **826**, **828** can be the same or different margins.

An arrow **808** is representative of a difference between a positive peak value of the gain controlled signal **802** and a positive threshold value. Similarly, an arrow **810** is representative of a difference between a negative peak value of the gain controlled signal **802** and a negative threshold value of the gain controlled signal **802**. The arrows **808**, **810** are representative of peak of the gain controlled signal **802** that are sufficient.

A difference **812** between another positive peak of the gain controlled signal **802** and an associated upper threshold is not sufficient. In essence, the difference **812** is smaller than the width of the region **826**. Referring briefly to FIG. **13**, the positive peak is compared with the threshold **806***b* by the comparator **752**. Noisy and marginal switching of the rotation signal **752***a* can result.

While the undesirable margin **812** can still result in switching of the output signal, e.g., the output signal **752***a* of FIG. **13**, any further change of the amplitude of the gain controlled signal **802**, as may result from temperature changes or wear of a gear assembly being sensed, can result in a missed switching of the output signal.

Category values **830** can be generated upon detection of each peak of the gain controlled signal **802**. The category values **830** are representative of passing and failing conditions of differences between the peak values and associated threshold values, i.e., whether cycle peaks of the gain controlled signal **802** fall within the respective regions **826**, **828**.

The category values **838** can be generated, for example, by the proper threshold detector **354** of FIG. **4** in accordance with difference values **808**, **810** and other difference values not explicitly shown.

While only two category values, 0 and 1, are shown, a third category value can be generated when the difference between the peak and the associated threshold has the wrong sign. The wrong sign would occur, for example, if a positive peak were below and associated upper threshold or a negative peak were above an associated lower threshold.

While two regions **826**, **828** are shown, in other embodiments, there can be additional similar regions associated with each threshold value, each region representative of a different aspect of passing or failing, i.e., various marginal passing conditions.

Identification of the upper and the lower amplitude regions **826**, **828** can be determined, for example, by the proper threshold detector **354** of FIG. **4**. The marginal or failing conditions can also be determined by the proper threshold detector **354** of FIG. **4**. The failing or marginal condition can be communicated by the self-test signal **178***aa* of FIG. **4**.

Referring now to FIG. **16**, in which like elements of FIGS. **14** and **15** are shown having like reference designations, the gain controlled signal **802** is shown, along with upper thresholds **806***a*, **806***b***860** and lower thresholds **804***a*, **804***b*, **858**.

PDAC values **814***a*, **814***b*, **846** correspond to the PDAC signal **736***a* of FIG. **13**. NDAC values **816***a*, **816***b*, **816***c*, **848** correspond to the NDAC signal **738***a* of FIG. **13**.

A plurality of upper regions **842***a*, **842***b*, **842***c* and a plurality of lower regions **844***a*, **844***b*, **844***c* are shown. The upper regions **842***a*, **842***b*, **842***c* have widths corresponding to a respective upper threshold value (e.g., **820**, **850**) plus a margin value. The lower regions **844***a*, **844***b*, **844***c* have widths corresponding to a respective lower threshold value (e.g., **824**, **852**) minus a margin value. The margin values can be the same or different. The margin values can also be constant regardless of the threshold values, or they can have values proportional to associated threshold values.

Unlike the upper and lower regions **826**, **828**, respectively, of FIG. **15**, which have substantially constant positions, the upper and lower regions **842***a*, **842***b*, **842***c* **844***a*, **844***b*, **844***c* of FIG. **16** can move with each one of the threshold values, each bounded on one side by a respective threshold value, which can move cycle to cycle. Function of the upper and lower regions **842***a*, **842***b*, **842***c*, **844***a*, **844***b*, **844***c* will be understood from the discussion above in conjunction with FIG. **15**.

Category values **858** can be generated upon detection of each peak of the gain controlled signal **802**. The category values **858** are representative of passing and failing conditions of differences between the peak values and associated threshold values, i.e., whether cycle peaks of the gain controlled signal **802** fall within the respective regions **842***a*, **842***b*, **842***c*, **844***a*, **844***b*, **844***c*.

The category values **858** can be generated, for example, by the proper threshold detector **354** of FIG. **4** in accordance with difference values **808**, **810** and other difference values not explicitly shown.

While regions **842***a*, **842***b*, **842***c*, **844***a*, **844***b*, **844***c* are shown, in other embodiments, there can be additional similar regions associated with each threshold value, each region representative of a different aspect of passing or failing, i.e., various marginal passing conditions.

Referring now to FIG. **17**, a method **860** is associated with the self-test signal **178***aa* of FIG. **4** and associated with the functions described above in conjunction with FIGS. **14-16**.

The method **860** begins at block **862**, where a gain controlled signal, for example, the gain controlled signal **168***a* of FIG. **4**, is received, for example, by the self-test module **178** of FIG. **4**, and, in particular, by the ADC **349** of FIG. **4**. At block **864**, a threshold signal, for example, the threshold signal **170***b* of FIG. **4**, is received, for example, by the self-test module **178** of FIG. **4**, and, in particular, by the ADC **348** of FIG. **4**.

At block **866**, the method **860** waits for either a command portion of the bidirectional signal **176***a* of FIG. **4**, or alternatively, waits for a particular state of one of the alternate control signals, for example, the power on signal **180***a* of FIG. **4** or the control signal **171***a* of FIG. **4**.

At block **868**, upon receiving the command or particular state of the alternate signal at block **866**, the method converts the gain controlled signal **168***a* of FIG. **4**, for example, with the ADC **349** of FIG. **4**.

At block **870**, upon receiving the command or particular state of the alternate signal at block **866**, the method converts the threshold signal **170***b* of FIG. **4**, for example, with the ADC **348** of FIG. **4**.

At block **872**, the self-test module **178**, and, in particular, the proper threshold detector **354** of FIG. **4**, identifies positive and negative peak values in the converted gain controlled signal.

At block **874**, the proper threshold detector **354** of FIG. **4** identifies threshold values in the converted threshold signal. The identified threshold values can be the same as or similar to the threshold values **804***a*, **804***b*, **804***c*, **806***a*, **806***b*, **806***c* of FIG. **14**.

At block **876**, the proper threshold detector **354** of FIG. **4** generates difference values by identifying differences between the peak values and associated threshold values. A difference value **808** is shown in FIG. **16**.

At block **878**, the difference values are categorized. For example, in some embodiments, ranges **842***a*, **842***b*, **842***c*, **844***a*, **844***cb*, **844***c* described above in conjunction with FIG. **16**, can be used to identify passing, failing, and marginal conditions of the difference signals.

At block **880**, the identified categories (e.g., category values) are communicated, for example, within the self-test signal **178***aa* of FIG. **4**.

While gain controlled signals are described above, as described above, in other embodiments, the gain controlled signal (generated by an AGC0 can be replaced by a fixed gain signal (generated by a fixed gain amplifier or a buffer).

While certain characteristic values (e.g., peak values) are shown in examples above, it should be recognized that other characteristic values can be used that are characteristic values of, related to, or associated with the proximity signal.

All references cited herein are hereby incorporated herein by reference in their entirety.

Having described preferred embodiments, which serve to illustrate various concepts, structures and techniques, which are the subject of this patent, it will now become apparent to those of ordinary skill in the art that other embodiments incorporating these concepts, structures and techniques may be used. Accordingly, it is submitted that that scope of the patent should not be limited to the described embodiments but rather should be limited only by the spirit and scope of the following claims.

What is claimed is:

1. A method of performing a self-test associated with a magnetic field sensor, comprising:

receiving a proximity signal responsive to a proximity of a sensed object with one or more magnetic field sensing elements disposed on a substrate; and

with a self-test module disposed on the substrate:

sampling the proximity signal, by analog sampling or digitally converting, to generate a plurality of analog samples or a plurality of digital samples, respectively, each digital sample comprising a plurality of digital bits;

selecting samples from among the plurality of analog or digital samples; and

communicating the selected samples to outside of the magnetic field sensor.

2. The method of claim **1**, wherein the selected samples correspond to amplitudes of selected peaks of the proximity signal.

3. The method of claim **2**, further comprising:

receiving a command signal from outside the magnetic field sensor to begin the communicating.

4. The method of claim **2**, further comprising:

receiving a command signal from outside of the magnetic field sensor to begin the sampling, the selecting, and the communicating.

5. The method of claim **1**, wherein the selected samples comprise substantially all of the plurality of analog samples or substantially all of the plurality of digital samples.

6. The method of claim **5**, further comprising:

receiving a command signal from outside the magnetic field sensor to begin the communicating.

7. The method of claim **5**, further comprising:

receiving a command signal from outside of the magnetic field sensor to begin the sampling, the selecting, and the communicating.

8. The method of claim **1**, wherein the sampling comprises the analog sampling.

9. The method of claim **1**, wherein the sampling comprises the digitally converting.

10. The method of claim **9**, wherein the selecting samples correspond to amplitudes of selected peaks of the proximity signal.

11. A magnetic field sensor, comprising:

a substrate;

one or more magnetic field sensing elements disposed on the substrate and configured to generate a proximity signal responsive to a proximity of a sensed object;

a self-test module disposed on the substrate, wherein the self-test module is coupled to receive the proximity signal, configured to sample the proximity signal, by analog sampling or digitally converting, to generate a plurality of analog samples or a plurality of digital samples, respectively, each digital sample comprising a plurality of digital bits, configured to select samples from among the plurality of analog or digital samples, and configured to communicate the selected samples to outside of the magnetic field sensor.

12. The magnetic field sensor of claim **11**, further comprising an analog-to digital converter coupled to receive the proximity signal and configured to sample, by digitally converting, the proximity signal to generate the plurality of digital samples.

13. The magnetic field sensor of claim **11**, wherein the selected samples comprise substantially all of the plurality of analog samples or substantially all of the plurality of digital samples.

14. The magnetic field sensor of claim **13**, further comprising:

an output format module configured to receive a command signal from outside the magnetic field sensor to begin the communicating.

15. The magnetic field sensor of claim **13**, further comprising:

an output format module configured to receive a command signal from outside of the magnetic field sensor to begin the sampling, the selecting, and the communicating.

16. The magnetic field sensor of claim **11**, wherein the self-test module is configured to sample, by analog sampling, the proximity signal to generate the plurality of analog samples.

17. The magnetic field sensor of claim **11**, wherein the self-test module is configured to sample, by digitally converting, the proximity signal to generate digital samples.

18. The magnetic field sensor of claim **17**, wherein the selected samples correspond to amplitudes of selected peaks of the proximity signal.

19. The magnetic field sensor of claim **11**, wherein the selected samples correspond to amplitudes of selected peaks of the proximity signal.

20. The magnetic field sensor of claim **19**, further comprising:

an output format module configured to receive a command signal from outside the magnetic field sensor to begin the communicating.

21. The magnetic field sensor of claim **19**, further comprising:

an output format module configured to receive a command signal from outside of the magnetic field sensor to begin the sampling, the selecting, and the communicating.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,068,859 B2
APPLICATION NO. : 13/526103
DATED : June 30, 2015
INVENTOR(S) : Daniel S. Dwyer et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the specification,

Column 4, line 10 delete “of magnetic” and replace with --of a magnetic--.

Column 4, line 25 delete “and variety” and replace with --and a variety--.

Column 7, line 4 delete “, there is can” and replace with --, there can--.

Column 8, line 14 delete “. And” and replace with --. An--.

Column 8, line 43 delete “threshold” and replace with --thresholds--.

Column 8, line 51 delete “a shown.” and replace with --as shown--.

Column 8, line 54 delete “gear 10 or FIG. 1” and replace with --gear 10 of FIG. 1--.

Column 11, line 30 delete “thing” and replace with --being--.

Column 13, line 27-28 delete “generated a result” and replace with --generated as a result--.

Column 13, line 31 delete “generated a result” and replace with --generated as a result--.

Column 14, line 13 delete “valley)” and replace with --valley).--.

Column 15, line 38 delete “262m 264” and replace with --262, 264--.

Column 16, line 21 delete “signals 264a, 264b,” and replace with --signal 264a, 264b,--.

Column 16, line 32 delete “signals” and replace with --signal--.

Column 16, line 65 delete “, 296aa,” and replace with --, 296a,--.

Column 16, line 67 delete “(AGCO” and replace with --(AGC)--.

Signed and Sealed this
Third Day of May, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office

Column 17, line 12 delete “that” and replace with --than--.

Column 17, line 25 delete “signals” and replace with --signal--.

Column 17, line 26 delete “circuits” and replace with --circuit--.

Column 17, line 64 delete “other” and replace with --another--.

Column 17, line 66 delete “signals” and replace with --signal--.

Column 19, line 45 delete “above described” and replace with --above-described--.

Column 19, line 46 delete “above described” and replace with --above-described--.

Column 20, lines 20-21 delete “. Diamond shaped” and replace with --. Diamond-shaped--.

Column 20, line 52 delete “a particular state of a particular state” and replace with --a particular state of--.

Column 21, line 53 delete “indicative a” and replace with --indicative of a--.

Column 21, lines 53-54 delete “zero indicative” and replace with --zero is indicative--.

Column 21, line 58 delete “condition.” and replace with --conditions.--.

Column 22, line 39 delete “indicative a” and replace with --indicative of a--.

Column 26, line 62 delete “indicative a” and replace with --indicative of a--.

Column 29, line 3 delete “of peak” and replace with --of a peak--.

Column 29, line 48 delete “, 806b860” and replace with --, 806b, 860--.

Column 30, line 62 delete “, 844cb,” and replace with --, 844b,--.

Column 31, line 3 delete “AGCO” and replace with --AGC)--.

Column 31, line 16 delete “that that” and replace with --that the--.

In the claims,

Column 31, line 59 delete “selecting” and replace with --selected--.